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ORGANIZATION OF THE BUREAU.

The Bureau of Economic Geology and Technology was established by the Board of Regents of The University of Texas, September, 1909. In so far as is possible with the means at hand this Bureau was designed to take the place of the University Mineral Survey, which was established by the Legislature in 1901 and discontinued in 1905. That survey was supported by direct appropriation, the fund being administered by the Board of Regents of the University. The present Bureau is maintained by the University, through a special item carried in the budget.

The laboratory of the Bureau was opened in September, 1910. with Mr. S. H. Worrell as chemist. In September, 1911, Dr. J. A. Udden became geologist for the Bureau and his first work was the preparation of this report on the oil and gas fields of Wichita and Clay Counties.

Exclusive of this Bulletin the following publications have been made by this Bureau:

"The Mineral Resources of Texas," Wm. B. Phillips, issued by the State Department of Agriculture as its Bulletin No. 14, July-August, 1910.

"The Composition of Texas Coals and Lignites and the Use of Producer Gas in Texas," by Wm. B. Phillips, S. H. Worrell and Drury McN. Phillips, University of Texas Bulletin No. 189, July, 1911.

"A map showing the location of iron ore deposits in east Texas, blast furnaces, lignite mines in operation, lignite outcrops, producing oil fields," etc., September, 1912, by Wm. B. Phillips.

In addition the following Press Letters have been issued and widely distributed:

Production and Value of Mineral Waters in Texas.
Clays and Clay Products.
The Fuel Situation in Texas.
Precious Stones in Texas.
Some Ornamental Stones from Texas.
The Iron Ore Situation in East Texas.

High Grade Kaolin in Texas.

Natural Gas in Texas.

The Testing Laboratory of the Bureau.

Phosphate Rock and Nitrate of Soda in Texas.

Production of Coal and Lignite in Texas in 1910.

A New Course in the Technology of Fuels.

Examination of the Oil and Gas Regions in Clay and Wichita Counties.

The Electra Oil Field, Wichita County.

Fuller's Earth in Texas.

Production of Petroleum in Texas.

The Mineral Production of Texas in 1910.

Some Conclusions as to the Oil and Gas Fields of Wichita and Clay Counties.

The several editions of these Press Letters are now exhausted.

In the laboratory the study of coals and lignites with reference to their gas producing properties is being continued and the question of briquetting lignites has been taken up.

Address all communications to Wm. B. Phillips, Director Bureau of Economic Geology and Technology, University, Austin, Texas.

The University of Texas Bulletin No. 246. *Plate XIV.*

The Electra Oil Field, March, 1912. Looking northwest.

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WM. B. PHILLIPS, Director

A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas

BY

J. A. UDDEN, Geologist of the Bureau,

ASSISTED BY
DRURY McN. PHILLIPS.

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The authors are particularly indebted to Prof. F. L. Whitney of the Department of Geology, University of Texas, for the care and skill with which he has made the photographs mentioned above.

A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas

By J. A. Udden and Drury McN. Phillips.

GENERAL STATEMENT.

The present study of the Electra oil field and the Petrolia gas field was undertaken with the purpose of learning the physical conditions which have brought about the accumulation of oil and gas in the Pennsylvanian sediments in Wichita and Clay Counties in the north part of the State. With this main object in view and with the limited time at our disposal our observations were mainly directed to features recognized as directly bearing on the immediate subject of the inquiry. Some observation bearing on the Tertiary and on the Quaternary geology of the region and on matters pertaining to geology in general were made only incidentally. The object of this report is similarly limited. This must account for the somewhat unusual form of the paper. It is not a succinct account of the entire geology of the region studied, nor is it entirely limited to the main subject of inquiry, since it appears desirable to place on record also some data incidentally secured. This report, therefore, partakes to some extent of the nature of an account of a special inquiry. To a lesser extent it is an account of a geological reconnaisance. The subjects of special inquiry, it will be perceived, were the stratigraphy and structure of the series of sediments in which the oil and gas occur. These sediments constitute several divisions of the Pennsylvanian series, together with what has come to be known as the Wichita formation.

THE EXPOSED ROCKS.

The Wichita formation is the main part of the bedrock which comes to the surface in the area studied. This rests on the Cisco formation. The surficial boundary between these two for mations in this region has been roughly outlined by earlier students of this region essentially as represented on the accompanying map.* See Plate I. No time was taken for adding any new local details to the course of this boundary, nor to study the criteria for its location.

The Wichita Formation.

On traversing the east half of Wichita County it appears that there were no beds which might be used for correlating all the different exposures. Few sandstones can be traced farther than a mile or two with any degree of certainty. It is only in the southwest part of the county that the stratigraphy and the structure may be worked out in the usual way, by correlation of parts of different sections.

FIELD EXPOSURES.

Opportunities to examine the bedrock in surface exposures in this region are not as many as in some other parts of the State. The best sections appear in the bluffs of the Wichita River. The entire region is one of old mature topography, where slopes are low and where the land is covered with a thin soil, through which the bed rock frequently protrudes, but mostly indistinctly. The streams have broad alluvial valleys, bordered by low bluffs, which are approached by the channels at long intervals. The alluvial plain of the Wichita averages more than three miles in width in Wichita County and the stream is sapping its bluffs in only some few places. The conditions are the same on the Red River, except that the alluvial valley is more irregular in width and that the points of attack by the stream on the bluffs are farther apart. Nevertheless a score and a half of places were selected where the terranes appeared in sufficient distinctness to warrant special descriptions. These follow below in order from east to west.

---

*W. F. Cummins, Geological Survey of Texas, Second Annual Report, pp. 357-552, Map. 1890. C. H. Gordon, George H. Girty and David White, The Wichita Formation of Northern Texas, Journal of Geology, Vol. XIX, pp. 110-134.

CLAY COUNTY.

Section 1. Section in the east bluff of Wichita River three-fourths of a mile northwest of Byers.

	Thickness in feet.
4. Gray sandstone, with a six inch layer of concretionary conglomerate, greenish gray in color	15
3. Red Clay	8
2. Bluish green shale	6
1. Talus	15
	44

Section 2. In a low bluff facing east, at a point about three miles west of Henrietta and one-half mile south of the Fort Worth and Denver Railroad there are some beds that have been explored for copper, which occurs in the forms of malachite, azurite and gray copper sulphide. The copper has accumulated mostly on the under surface of some carbonaceous clay bands, in cavities once filled with plant remains, and also in some joints in sandstone. The section exposed, partly in an old excavation, is as follows:

	Thickness in Feet.	Inches.
9. Sandstone	8	
8. Black shale		4
7. Sandstone containing carbonaceous shreds of leaves and other vegetation		6
6. Black shale, with a more or less continuous infiltration of copper ore against its lower surface		4
5. Sandstone containing shreds of vegetation		6
4. Black shale, with frequent incrustations of copper ore on the lower surface		2
3. Shale and sandstone	2	
2. Sandstone, impregnated with copper along some joints and containing some impressions of tree stems and other remains of vegetation, which are partly filled with copper ore	2	
1. Shale	1+	
	14+	8

Section 3. About three miles northeast of Wichita Falls a low bluff, facing westward, runs for almost a mile in a general north and south direction. At the north end the strata exposed in this escarpment form an isolated butte. The section in this butte is as follows:

	Thickness in feet.
5. Gray sandstone, soft and homogeneous in some places. In other places concretionary, cross-bedded, or cemented by interstitial lime to a hard rock. This sandstone forms the cap of the escarpment. Maximum thickness.....	8
4. Gray and blotched brown shale, sandy in places and containing calcareous concretions........	8
3. Red shale, with here and there gray blotches and streaks..................................	11
2. Gray sandstone, much cross-bedded, partly straightly and thinly laminated............	3
1. Shale, gray and brownish, with many dark calcareous concretions........................	15
	45

WICHITA COUNTY.

Section 4. At the southeast corner of the Walker-Harvey survey, two and one-half miles northeast of the Union Station at Wichita Falls, a sandstone twelve feet thick, is seen in the low bluff. This sandstone rests on some twenty feet of red and gray shale.

Section 5. In the cut of the Missouri, Kansas and Texas Railroad, on a hill about one mile east of Wichita Falls, a sandstone is exposed which is composed of alternations of flat laminated layers and cross-bedded layers from two inches to a foot thick. Some of the uppermost layers are black from impregnations of iron and manganese oxide.

Section 6. One and one-half miles southeast of Wichita Falls, a low bluff facing west and south follows the east side of an irrigation canal. This bluff consists of five feet of red and blue shale. There is also some conglomerate. The sandstone is typical of this region. It consists of mostly white and subangular quartz, but with some red and pink grains. It is frequently cross-bedded, and the cross-bedded layers alternate with thin, straight layers, lying horizontally. Some of these show extended surfaces, almost perfectly plain and smooth. Small spherical concretions were noted in which the grains of sand were cemented together with calcite or with oxides of iron and manganese. The thickest homogeneous or unstratified layer noted was two feet. Under the sand in some places and interbedded with the lower part of the sand in another place were layers of conglomerate mostly less than a foot thick. This consists of lumps of limey and marly materials and lumps of clay, mostly from one-half to one-third inch in diameter.

The shale is red with bluish-white streaks and blotches. In one place it was cut by a vertical vein of hard red calcareous material, one and one-half inches thick.

Section 7. In the south bank of the Wichita River, about three-fourths of a mile southwest from the Fort Worth and Denver Railroad bridge, the bed rock is exposed for a considerable distance and extends up into the bluff. The exposed section is as follows:

	Thickness in feet.
7. Thin-bedded red sandstone of fine texture, consisting of straight, smooth, and persistent layers from one-eighth to one-half inch thick..	4
6. Red shale with thin blue layers containing streaks of conglomerate consisting of calcareous concretions mixed with lumps of clay, both kinds averaging one-fourth inch in diameter	2
5. Red shale, containing scattered concretions of from one-third of an inch to three inches in diameter. Many of the largest concretions have an irregularly mammilated surface......	25
4. Sandy brown shale........................	1
3. Sandstone, laminated and wavy-bedded......	6
2. Shale, brown and blue, in places consisting of lumps, as if brecciated, or as if it were a conglomerate of mud lumps....................	1½
1. Brown and blue shale with lentils of sand, one foot thick, extending down below water level in the stream............................	3
	42½

Section 8. Near the pavilion at the north end of Wichita Lake, the strata seen consist of:

	Thickness in feet.
4. Gray sandstone	2
3. Red Clay	8
2. Soft white sandstone	3
1. Red clay	2+
	15+

Section 9. About three-fourths of a mile southwest of the E. F. Austin survey, and some two and one-half miles southwest from the railroad station in Wichita Falls are some gullies in the upland. The beds exposed are as below:

	Thickness in feet.
2. Gray sandstone	2
1. Shale, mostly red, with sandy layers with concretions, and thin seams of satin spar gypsum, of a bright orange color	20
	22

Section 10. About four miles south of Burkburnett the Wichita Falls and Northwestern Railroad bed is cut into a low hill a mile south of the main creek running east into Red River. The west bank of this cut shows some cross-bedded sandstone which lies in an old channel evidently cut into the red clay by the currents which deposited the sand. It appears that the current was shifted northward as there was a greater filling-in of sand on the north side. The current must have been thrown back and forth, for along one plane in the main sand deposit on the north side it is clear that the sand below this plane was eroded before the overlying sand was deposited. Later the entire channel was filled with red clay. See fig. 1.

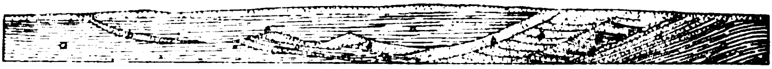


FIG. 1. Section in a cut along the Wichita Falls & Northwestern Railway, three and a half miles south of Burkburnett, Wichita County: a, red shale; b, cross-bedded sand; c, erosional unconformity; d, alternating layers of silt and sand.

Section 11. In the northwest quarter of the W. W. Carroll survey, about six miles north and four miles east of Iowa Park, an exposure shows some slanting sandstone overlain by a few feet of red shale in which there is a thin shell of limestone which lies horizontal.

Section 12. On a hillside near the west side on survey 2, Tarrant County School Land, about three miles north and one mile east of Iowa Park, is a thin dark, sandy limestone, resembling the limestone seen near Burk Station and on Beaver Creek. It is only a few inches thick.

Section 13. In the Red River bluffs on the A. A. Durfee survey, almost due north from Iowa Park, outcrops of the Wichita beds are seen for a distance of some two miles. A section was taken where the bedrock is highest, and this is as below:

		Thickness in feet.
10.	Dark red, sandy shale with seams of dark red sandstone from one to two inches thick	8
9.	Laminated dark red sandstone	1½
8.	Conglomerate of concretions and lumps of mud, dark red, with thin intercalated layers of sandstone	3
7.	Laminated and cross-bedded rusty red and gray sandstone	2
6.	Red clay with a six-inch stratum of calcareous light blue shale ten feet above its base. The red clay contains blotched gray concretions a half foot in diameter	15
5.	Gray, calcareous and sandy rock	1½
4.	Red shale, in part sandy	15
3.	Calcareous sandstone with fragments of fossils, in places with many sizes and kinds of concretions. The lower side of this stratum has combs or narrow projecting ridges which fit in the underlying clay	1
2.	Variegated shale, with calcareous concretions	6
1.	Red shale	12
		65

The calcareous seam in number 6 of the above section was noted a half mile farther west in the bluff.

Section 14. One of the deepest sections in the east part of Wichita County is seen on the side of an elongated hill about four miles south of Wichita River, and a short distance north of School Number 18. The following is a description of the section seen on the north side of this hill:

	Thickness in feet.
3. Sandstone, gray, cross-bedded. The thickest single layer of sandstone noted was three feet	15
2. Brown and red shale........................	65
1. A layer of many large and small calcareous knotty concretions, weathering black, evidently from manganese........................	1
	—
	81

Section 15. Near the boundary between blocks 6 and 7 of the Palo Pinto County School Land, and about a mile and three-fourths southwest from School Number 18, a long ridge runs east and west, on the side of which the following section was noted:

	Thickness in feet.
4. Gray sand........................	5
3. Red clay........................	20
2. Ashen white sand, soft and of rather fine grain. About the middle of this stratum is a black conglomerate consisting of calcareous clay lump pebbles about one-fourth of an inch in diameter and quite uniform in size..	7
1. Red clay........................	7
	—
	39

Section 16. In the west side of the road running north and south along the east side of B. S. and F. survey, one mile west of School Number 9, and about nine miles north and two miles west of Iowa Park, there is a thin shell of light gray limestone overlying some gray shale. This limstone contains unrecognizable organic fragments throughout, and a small coral and a fish scale were noted. It changes into a sandy calcareous rock in a short distance to the northeast. A thousand feet to the northeast from this place there is an exposure in the east bank of the creek, which

probably lies twenty or thirty feet below the above limestone In this exposure is seen a typical instance of contemporaneous erosion in the Wichita formation. A thin gravel of washed concretions lies on a contemporaneously eroded bed of red shale, and over this, a half foot of shale and then three feet of sand, with another streak of soft conglomerate. See fig. 2.

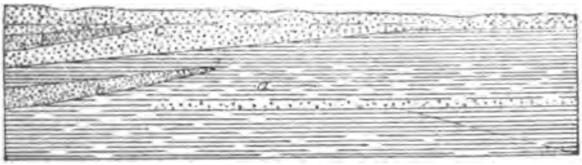


FIG. 2. Wichita beds exposed in the bank of a creek in T. T. Railway Company survey, 9 miles north and 2 miles west of Iowa Park, Wichita County: a, shale; b, conglomerate; c, sandstone.

Section 17. In the south end of the T. E. and L. Co. survey abutting on Red River, about two and one-half miles west of School Number 9, and nine miles west of Burkburnett, a section appearing in the right bank of Cavalry Creek is as follows:

	Thickness in feet.
6. Sandstone and concretion conglomerate	1
5. Ashen gray and red shale	5
4. Streaks of sand and concretionary conglomerate	2
3. Ashen gray and red shale	10
2. Streaks of shale, with indistinct remains of vegetation	1
1. Gray shale with streaks of sand and concretionary conglomerate	2
	21

Section 18. The section seen in Finder's Butte, which is located north of the south boundary of Wichita County, due south from School Number 6, is as below:

	Thickness in feet.
2. Gray structureless soft sandstone	5
1. Red clay with thin streaks of sand in the lower part	20
	25

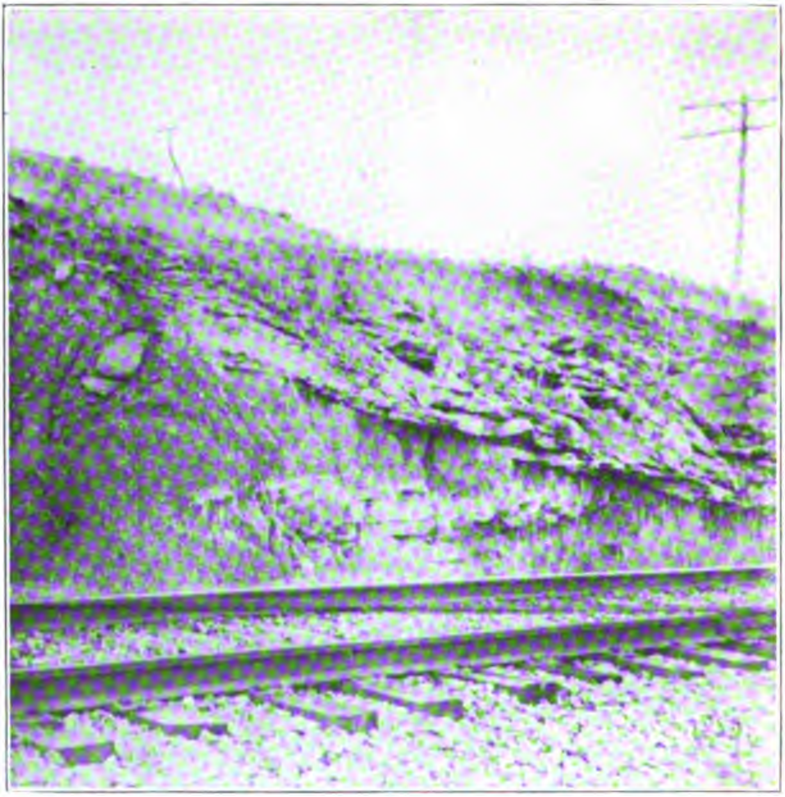
Section 19. In the southeast quarter of the W. C. Eustis survey, about two miles north of Burk Station, two sandstones appear, one in the bottom of the main creek, and one caps the low bluff west of the creek. They are separated by twenty-five feet of red shale, containing many concretions in its upper part. The upper sandstone capping the upland on the west side of the creek is quite regularly cross-bedded, and where it has been eroded below its upper surface the slanting cross-beds show a deceptive resemblance to an outcrop of highly tilted strata of considerable thickness. This is seen in several places just back of the west bluff of the creek.

Section 20. Near the north boundary of the C. T. R. R. Co. survey abutting on Wichita River, about six miles west and one and one-fourth miles south of the railroad station at Iowa Park, there is an eroded bluff showing the following section:

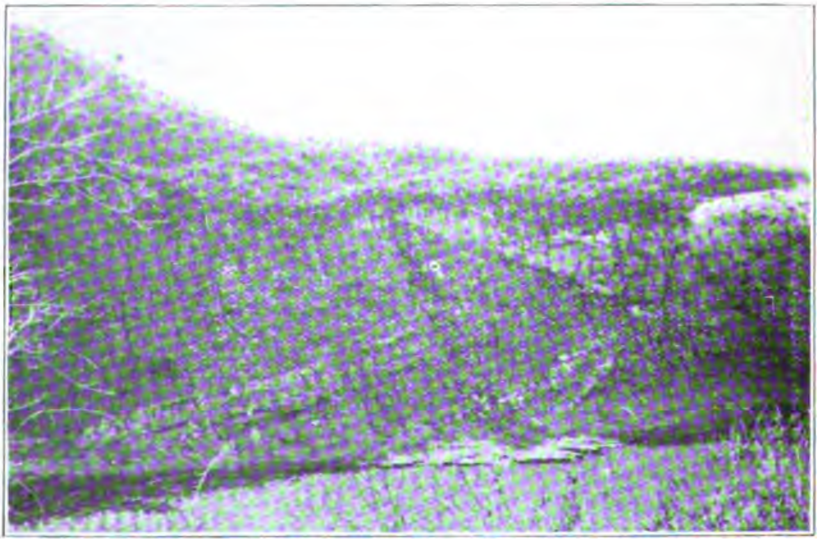
	Thickness in feet.
4. White sandstone, in part cross-bedded.......	4
3. Red clay with many concretions and here and there some sandy streaks..................	15
2. Red sandstone, with cross-bedded structure. This member terminates somewhat abruptly when followed westward..................	10
1. Red shale with white streaks, and with some thin layers of a conglomerate consisting of worn concretions, evidently assorted........	15
	44

The lower sandstone, or a sandstone having the same level in the red shale, runs south in a low escarpment for almost a mile and is again well exposed in some bluffs just south of the main wagon road. At this point it was seen to contain an impression of a fern leaf, like *Pecopteris tenuinervis* F. and W.

Section 21. Near the southeast corner of the B. S. and F. survey, about five miles southwest of Burk Station, the following section appears in a gully:



A. Contemporaneous unconformity seen in a railroad cut 2 miles west of Petrolia, Clay County. Looking east.



B. Exposure in the right bank of China Creek in Block 314, Waggoner Colony Survey, 7½ miles north and 4 miles east of Electra, Wichita County. Looking south. Photograph by I. J. Broman.

	Thickness. in feet.
4. Dark limestone	½
3. Red and blue shale	15
2. Sandstone, about	4
1. Red and blue shale	20+
	39½+

About a mile northeast from this place the limestone in the above section is overlain by some six feet of sandstone, and some dichotomously fluted vertebrate teeth were noted in the limestone.

Section 22. In block 314 of the Waggoner Colony survey, about seven and one-half miles north and four miles east of Electra, in the right bank of China Creek, is an exposure of red clay and sandstone, which shows unconformities in bedding. Farthest east is a bank of red clay, some thirty feet high, and this is capped for most of its length by several feet of sandstone. At its eastern edge this sandstone terminates against a rising slope of the clay, like the bank of an old channel. At the west end of the exposure two rising sandy layers have been cut off in the excavation of a contemporaneous channel, or hollow, which later has been filled with sand. See fig. 3 and Plate XV, B.

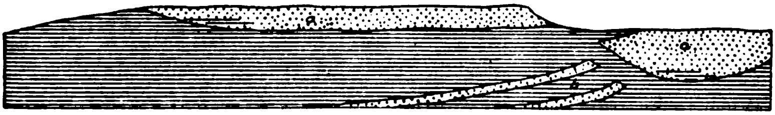


Fig. 3. Exposure in the right bank of China Creek in Block 314, Waggoner Colony survey, 7½ miles north and 4 miles east of Electra, Wichita County. Two sandstone beds, rising from left to right, have been bevelled off. Some clay was later deposited on the eroded slope. The depression was later filled with sand, which overlaps at the right. See also Plate XV, B.

Section 23. On the south side of a projecting upland, about six miles west and two miles south of Burk Station, the following section was noted:

	Thickness in feet.
5. Shale	8
4. Dark gray limestone	½
3. Red shale	20
2. Sandstone, cross-bedded	4
1. Blue shale	8
	40½

Section 24. In the bluffs on the north side of Beaver Creek, on the H. & T. C. R. R. Co. survey number 35, about seven and one-half miles south and two and one-half miles east of Electra, the following section was noted:

	Thickness in feet.
8. Conglomerate of late Tertiary (?) age	3
7. White sandstone, top of Wichita beds in this section	7
6. Sandy gray shale	4
5. Red shale	10
4. Gray shale, with shells of lime and sand	6
3. Dark gray limestone	1½
2. Gray and bluish-gray shale	7
1. Red shale, containing at 18 feet from top a nine-foot white sandstone, which runs out in the section in a short distance to the east	33
	71½

Section 25. In the north bluff of the Wichita River near the west line of the L. T. Miller survey, about eleven miles south and one mile east of Electra, is the highest single exposure of the Wichita beds in Wichita County. It measures 130 feet, and is as below:

	Thickness in feet.
17. Gray shale with thin shells of lime	3
16. Gray limestone of fine texture	2½
15. Bluish gray shale, weathering yellow	16
14. Sand and shale, purplish in color	3
13. Blotched gray and red shale	2
12. Gray sand, cross-bedded	5
11. Yellow and red clay, mostly red in the upper part	23

10. Dull red, silty, soft sandstone, mingled with gray layers	5
9. Gray muddy shale, cross-bedded sandstone and conglomerate consisting of concretions	4
8. Red clay with some gray blotches	10
7. Red clay	16
6. Sand and mottled clay	2
5. Red clayey shale	17
4. Gray sandstone, soft	1
3. Red soft sandstone, cross-bedded	8
2. Blotched, gray and red shale, with layers of gray sand, from one-eighth to one-half inch thick	2
1. Mottled brown and gray shale, mostly brown	11
	130½

Sections 26 and 27. In the west part of the J. A. Roesh survey, about one and one-half miles south of Electra the section seen in the hillsides near an earth tank is as below:

	Thickness in feet.
5. Surface material and some shale	5
4. A slightly sandy layer in shale, containing calcareous concretions. These are mostly from one-half to two-thirds of an inch in diameter, sub-spherical and smooth. Some are compound, consisting of several concretions coalesced into one	1
3. Red clay, or shale	6
2. Blue clay	9
1. White sandstone	4
	25

Half a mile from this point and a little to the west, on the west side of the Electra road, the same section recurs, but here number 4 is capped by a three to four inch sandy limestone, which contains *Estheria minuta* Jones (determined by Dr. J. W. Beede) in considerable numbers. It also contains pieces of imbedded bones and occasional teeth of vertebrates. This bed was again seen a half mile farther west, where a worn fragment of *Myalina Swallovi* McChesney (?) was noted. The sandstone is here marked by vertical straight perforations. The section seen in a bluff facing south near this place is as follows:

	Thickness in feet.
3. Red clay, containing some blue and gray streaks	30
2. Sandstone, with vertical narrow perforations.	½
1. Red Shale	1
	31½

Section 28. In the east bluffs of a north tributary to Beaver Creek near the west line of H. & T. C. R. R. Co. survey 25, about six and a half miles south and one mile west of Electra, the section is as below:

	Thickness in feet.
5. Gray sandstone	2
4. Red shale, with concretions	30
3. Streaks of sandstone, with calcareous layers and frequent fragments of vertebrate bones	2
2. Blue shale	6
1. Red shale	2
	42

Section 29. A section near the south end of the water reservoir one mile west of Electra is as below:

	Thickness in feet.
3. Red and some blue shale, about	20
2. Gray sandstone	2
1. Blue shale	3
	25

WILBARGER COUNTY.

Section 30. A section near the northwest corner of the H. & T. C. R. R. Co. survey 27, about four miles south and two miles west of Electra:

	Thickness in feet.
3. In a well bored for water near this place a dark gray thin limestone was penetrated at the depth of about 45 feet. Fragments of this limestone were seen on the old dump and it was clearly	

identical with the Beaver Creek limestone. The curb of the well is about twenty feet under a calcareous stratum containing fragments of vertebrate bones, capping a low bluff near this place. The beds between this layer and the limestone in the well consist of red and blue shales, with some sandy layers and streaks of black shale. This shale contains some black impressions of plant leaves. Calcareous sandstone or a concretionary layer caps the adjacent low bluffs	1
2. Red and blue shale, the latter with plant remains, partly exposed, and also partly explored in the well	65
1. Dark gray limestone containing *Syringopora* and *Estheria minuta* Jones	1
	67

Section 31. About three-fourths of a mile northwest of the Webb Well, on the H. & T. C. R. R. Co. survey 21, about four miles south and two miles west of Electra, a disintegrated gray limestone outcrops on the edge of a low rise in the upland, at an elevation of about 60 feet above Bluff Creek. It is underlain by some gray and red shale, and contains many invertebrate fossils which have suffered weathering and lie scattered on the slope. The forms identified with some doubt are as follows:

	Number noted of each.
Syringopora, sp	12
Cythere, sp	Many
Allorisma terminale Hall	15
Myalina aviculoides M. and W.	8
Temnocheilus winslovi M and W	11
Nautilus excentricus M. and H.	3
Bellerophon crassus M. and W.	30
Pleurotomaria, sp	6
Murchisonia, sp	6

GENERAL DESCRIPTION OF THE WICHITA ROCKS.

It is believed that these sections represent different parts of a general section some three hundred feet thick. They are known to include successive strata measuring about two hundred and twenty-five feet, and constituting the uppermost beds exposed in the field examined.

We will regard these sections first as a group representative of a single formation. They all occur within the areal limits of what has come to be known as the Wichita formation.* The thickest section measures only 130 feet in all, and most of them fall short of fifty feet. The total number of feet of rock described is only a few feet more than 1000. Some items are known to be repeated descriptions of the same strata, in places where the sections are not very far apart, and many more of them must include beds that are synchronous and were made at the same time.

From these sections we may obtain a fairly close estimate of the gross nature of the formation. As seen in the exposures, it consists of shales, sandstones, conglomerates and limestones, named in order of their rank as to bulk. Seventy-nine per cent of the total thickness described in the section consists of shale, twenty per cent of sandstone, and less than one per cent each of conglomerate and limestone. There are also gradations between all of these groups. It is believed that the percentage of sandstones determined in this manner is higher than the actual percentage of sandstone in the formation, as this rock stands weathering better than the shales and is hence more frequently preserved in the outcrops. But the difference between the actual and apparent ratios of sandstone and shale can not be very great. In section 25 above, where there is a total of 124 feet of shale and sand the percentage of shale is 83 and that of sandstone 17. The relative quantities of different rocks are shown in the following table, in which the several rocks described and measured in the sections are classified, summed up, and reduced to percentages.

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*W. F. Cummins, First Annual Report of the Geological Survey of Texas, 1889, p. 186. C. H. Gordon, George H. Girty and David White, Journal of Geology, Vol. 19, 1911, pp. 110-134, and others.

TABLE SHOWING TOTAL THICKNESSES IN FEET AND PERCENTAGES OF DIFFERENT KINDS OF ROCKS DESCRIBED IN SECTIONS SEEN IN WICHITA AND CLAY COUNTIES.

	Total feet.	Percent. of total feet.
Shale	789	79
Red shale	(580)	(58)
Red and blue shale	(113)	(11)
Blue shale	(96)	(10)
Sandstone	201	20
Conglomerate	8	.5
Limestone	6	.5
Total	1004	100

AVERAGE THICKNESS OF DIFFERENT BEDS.

The beds described vary in thickness from less than one foot to sixty feet. Not one of the conglomerates or limestones is more than three feet thick and only eleven instances were noted of sandstones exceeding five feet. Of these only three were more than ten feet, while none exceeded fifteen feet. The shales are more heavily bedded. In forty-three instances these measure more than five feet thick, while there were only twenty-three beds of shale measuring less than five feet. These relations are more fully presented in the following table.

TABLE SHOWING FREQUENCY OF DIFFERENT THICKNESSES OF STRATA AS DESCRIBED IN THE SECTIONS NOTED IN CLAY AND WICHITA COUNTIES.

Measured thickness in feet.	1-5	6-10	11-15	16-20	21-25	26-30	41-45	61-65
Number of shale beds	23	17	11	9	3	3	1	1
Number of sandstones	32	8	3	------	------	------	------	------
Number of conglomerates	10	------	------	------	------	------	------	------
Number of limestones	8	------	------	------	------	------	------	------
Number of all kinds of rocks	73	25	14	9	3	3	1	1

THE WICHITA SHALES.

From the observations made in the field it appears that about seventy-three per cent of the bulk of the shales of the exposed Wichita formation consists of greenish, bluish or light gray shale, and about thirteen per cent consists of alternating layers of red and gray shale or blotched red and gray shale. The greater part of this shale is fine in texture, containing very few quartz grains which measure more than one-sixteenth of a millimeter in diameter.

The Gray and Blue Shale.

The bluish gray or greenish gray shales are usually found under the sandstones and limestones. We also find, in similar situations, streaky or blotched mixtures of gray and red shale.

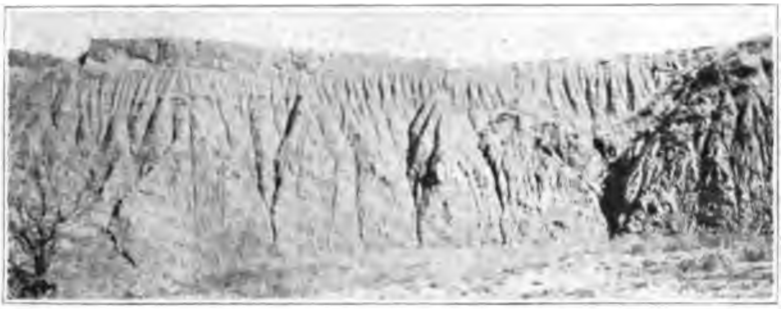
The gray or bluish gray shale frequently contains minute fragments of chitinous, brown translucent fragments of scales of fishes, which sometimes also are found entire. In some of the blue shales these fragments are found in large numbers. Examining some entire scales we find most of them rhombic in outline, or quadrangular-oblong, sometimes with dim concentric contours. See fig. 4, 1-4. In one specimen there were two parallel vessels or grooves, from which smaller short vertical vessels extended. Fig. 4, 7. Some of the chitinous framgents have a system of lacunar cavities, from which radiate small tubules closely imitating in form branching processes of nerve cells. Fig. 4, 5. These scales are evidently from ganoid fishes, possibly such as *Platysomus* or *Paleoniscus.*

Where the gray shales are dark they frequently contain minute imbedded shreds of vegetation and even entire leaves. Bituminous matter is also occasionally present in quantity sufficient to produce a bituminous odor when a fragment of the shale is heated in a closed tube. When large concretions occur in this shale they are usually flat and consist of lime or of carbonate of iron. Small crystals of marcasite also occur. These, as well as the concretions, have often been oxidized, the concretions being more or less completely changed to limonite and the marcasite appearing as rusty specks in the shale.

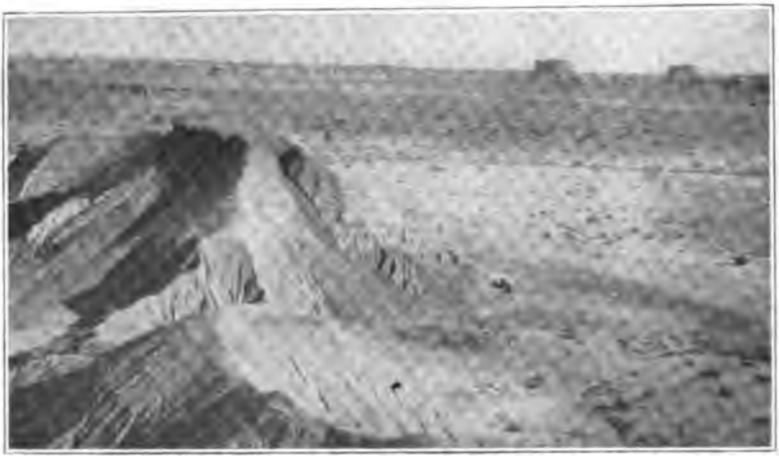
The Red Shale.

The red shale constitutes the greater part of the exposed Wichita formation. The red color is due to the presence of hematitic material. The red tints vary from yellow to light red, dark red, purple, brown and dark brown. Some of the red shales are highly ferruginous, containing no less than ten per cent of oxide of iron. These are generally very fine in texture. The usual percentage of ferruginous material is very much less, probably less than five per cent.

In its texture the red shale is very much like the blue shale, and varies from very fine material to sandy shale. A small part



A. Typical erosion forms of the Wichita red clays, south bank of China Creek, 7½ miles north and 4 miles east of Electra, Wichita County. Looking east.



B. Bad lands topography in the red Wichita shales, 1 mile west of Electra, Wichita County. Looking north.

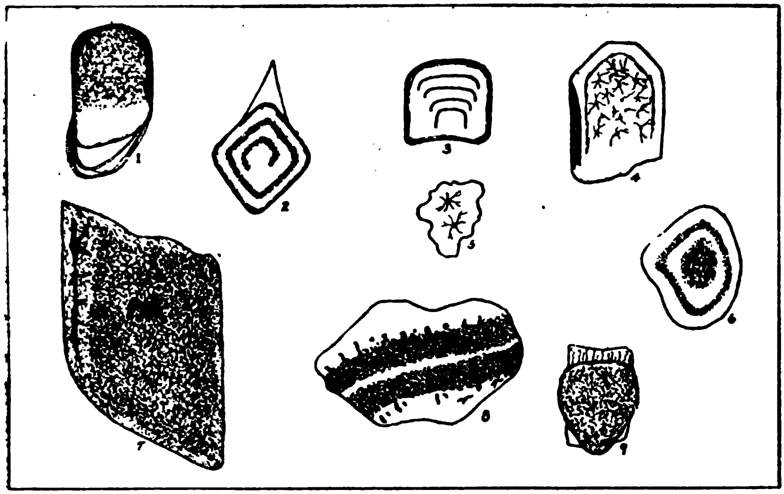


FIG. 4. Fish scales from blue clay in the south part of H. & T. C. Ry. Co. Survey 1, five miles west and one-half mile south of Burk, Wichita County. Numbers 1, 2, 3, 6, 7, 8, and 9 are magnified about 30 diameters, and numbers 4, 5, about 100 diameters. The latter show cavities from which some minute canals radiate. Large canals, like Haversian vessels, are seen in 7. Numbers 1, 2, 3, 4, 6, 7, and 9 are entire scales. Numbers 5 and 6 are fragments.

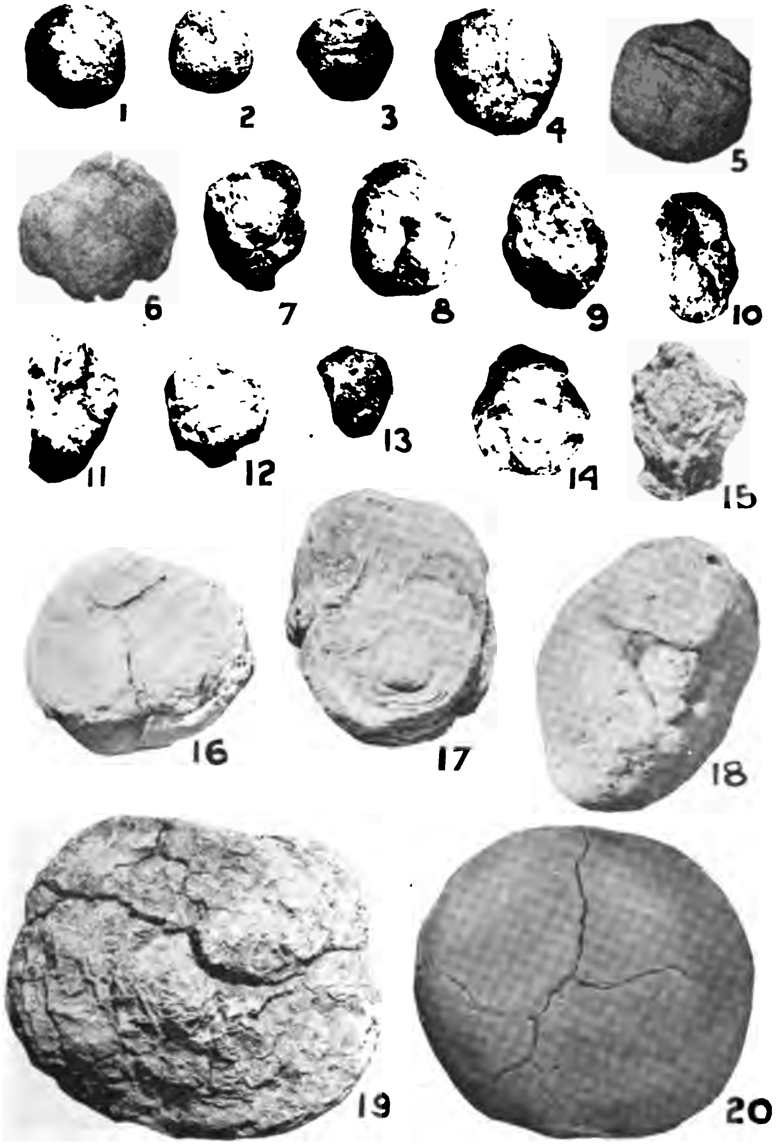
of the shale consists of quartz grains measuring more than one-sixteenth of a millimeter in diameter. With this ingredient there are usually some scales of mica. The hematitic material is present in a state of extremely fine subdivision.

The red shale is in many cases somewhat obscurely stratified, showing hardly any lamination or other perceptible structure in beds several feet thick. In places where it is mingled with gray or white layers, the stratification is very trenchantly shown. See Plate XVI, B. In some such exposures contemporaneous unconformities are to be seen, where a series of overlying laminated shales bend in conformity to the surface of a local excavation in an underlying horizontally stratified clay or shale. See fig. 2.

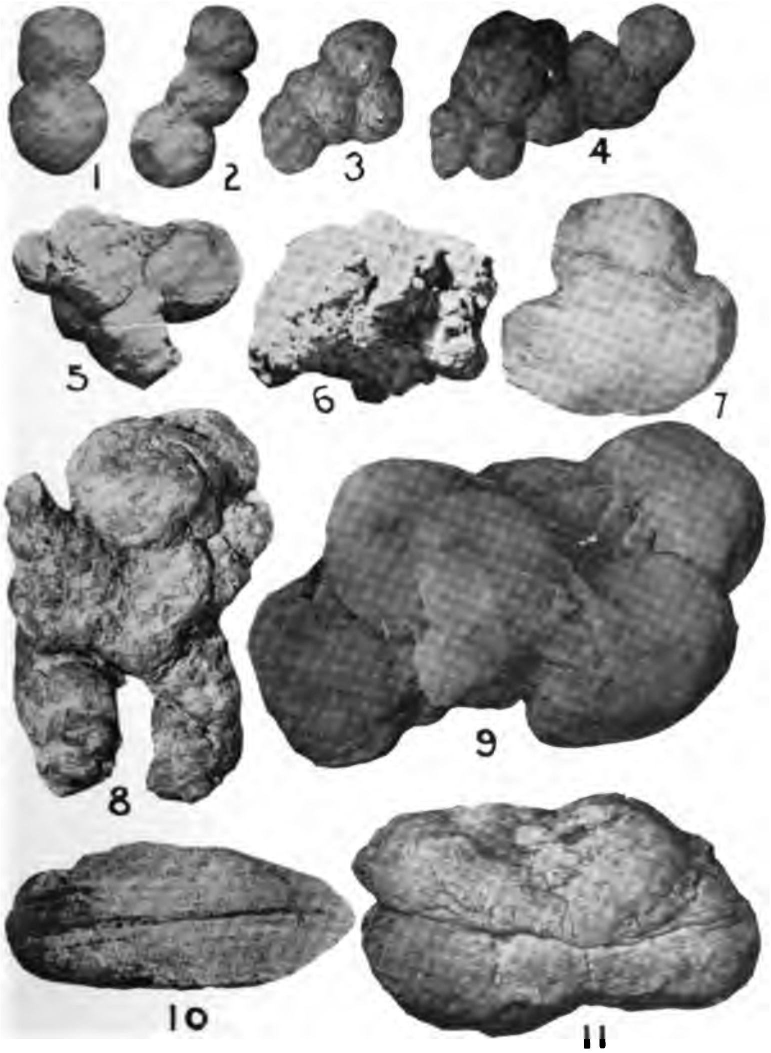
Concretions in the Shale.

The red shale usually contains numerous concretions of material which once no doubt was disseminated generally through the body of the shale. Eroded slopes of this shale are frequently closely strewn with these concretions, which remain intact on the surface after the rains have washed away the readily disintegrated matrix in which the concretions were originally formed and imbedded. The common form of the concretions is an irregular spheroid and the usual sizes are from half an inch to four or five inches in diameter. They usually have a very irregular exterior surface, which in some may be described as irregularly botryoidal, as mammillated, pitted, furrowed. ridged, or which may be so entirely irregular as to defy any general description. Such are the greater number. Only in rare cases are some found with a smooth outer surface. In some cases they approach a cylindric form, and it appears that such concretions have started to form either in some tubular cavities in the shale or around some narrow cylindrical bodies buried in the shale, for some such concretions still show traces of a centrally located tubular cavity. Some concretions of this form were noted at a horizon in a red shale, which in another place, a mile distant, contains sandy layers with fossil leaves, and the suggestion prompts itself that these concretions have grown around roots or small branches of plants originally imbedded in the shale. Some of these concretions were seen to have had an inclined position in the strata. Another instance of cylindric forms was noted in some sandy shales. In this case concretionary lime had cemented the fine sand along a line vertical or slightly inclined to the stratification planes, causing a cylindric or rather double cone-shaped form to weather out from the shale.

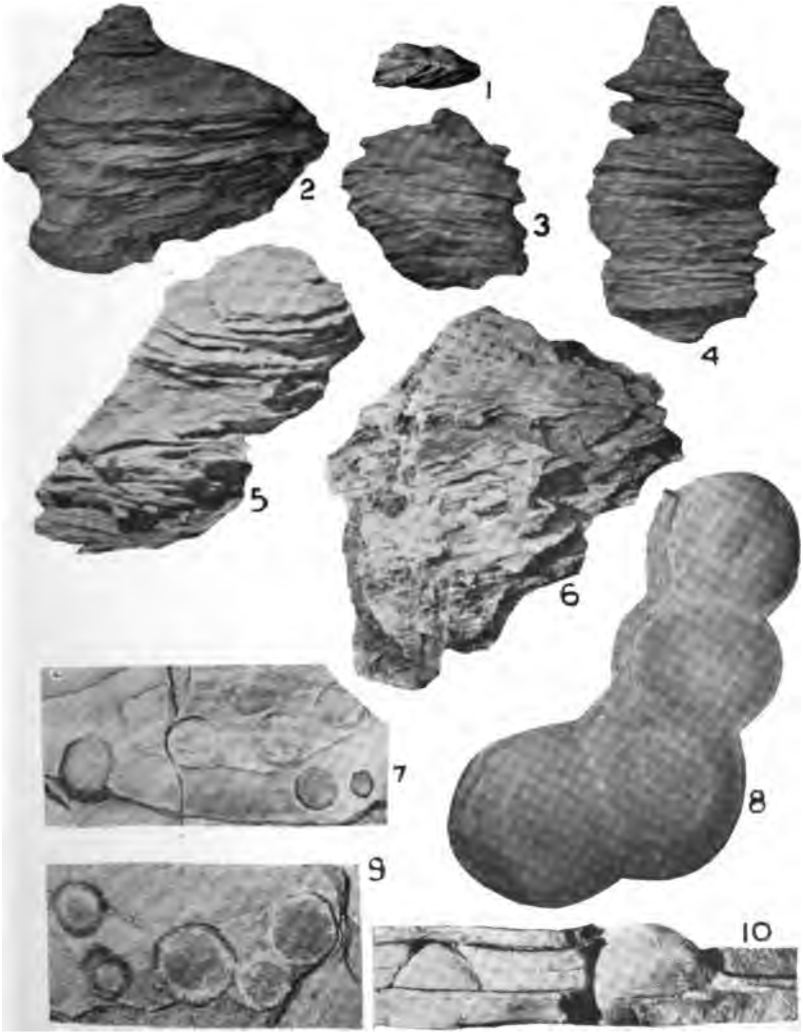
In some places the concretionary material has been deposited along certain structures in the shale, as along sandy layers, or in joints which have developed in the clay. When these joints have opened up in the process the concretionary material takes the form of irregular fissure veins. Some calcareous veins of this kind were noted in a shale bank a short distance northeast from Electra. A system of intersecting joints, closely set, seem to have been developed in the clayey matrix next to some of the large concretions with the result that the calcareous filling in these fissures extends out and away from the concretions and forms an irregular network of ridges on their surfaces. The mammillated and irregularly botryoidal surface on some concretions is clearly the result of an interruption of the concre-



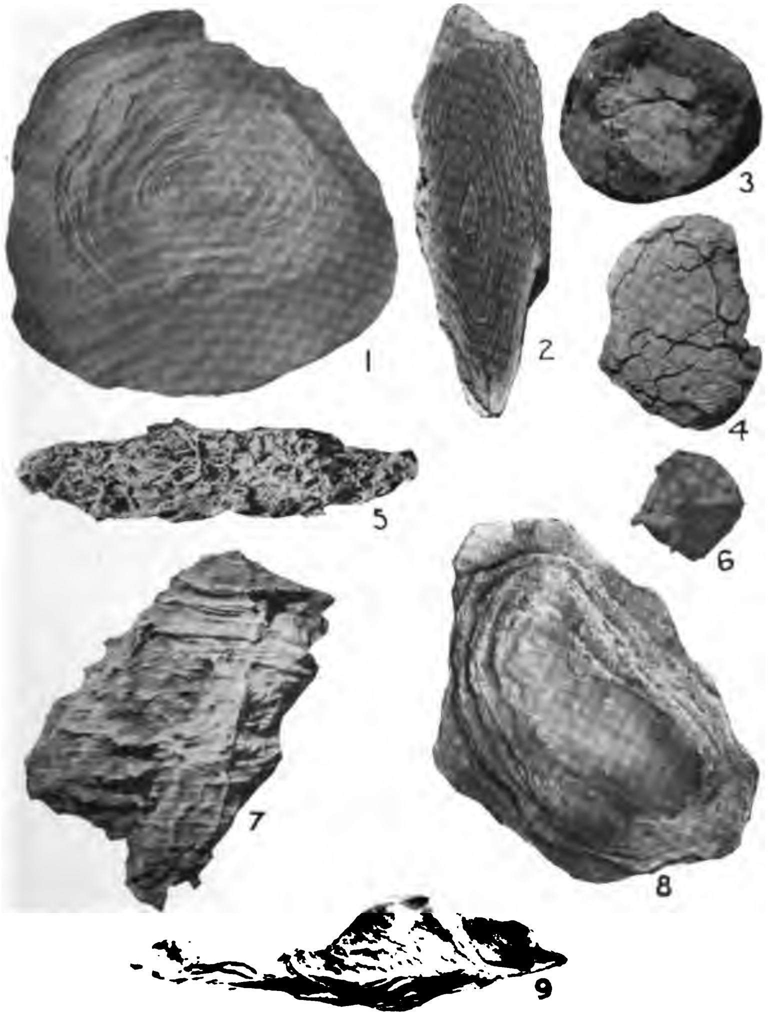
Concretions from the Wichita clays: 1-5, spherical forms; 6-15, irregular spheroids; 16, 19, 20, concretions showing shrinkage cracks; 17, a fractured specimen showing concentric structure; 18, a smaller concretion included in a larger. Photographs by F. L. Whitney.



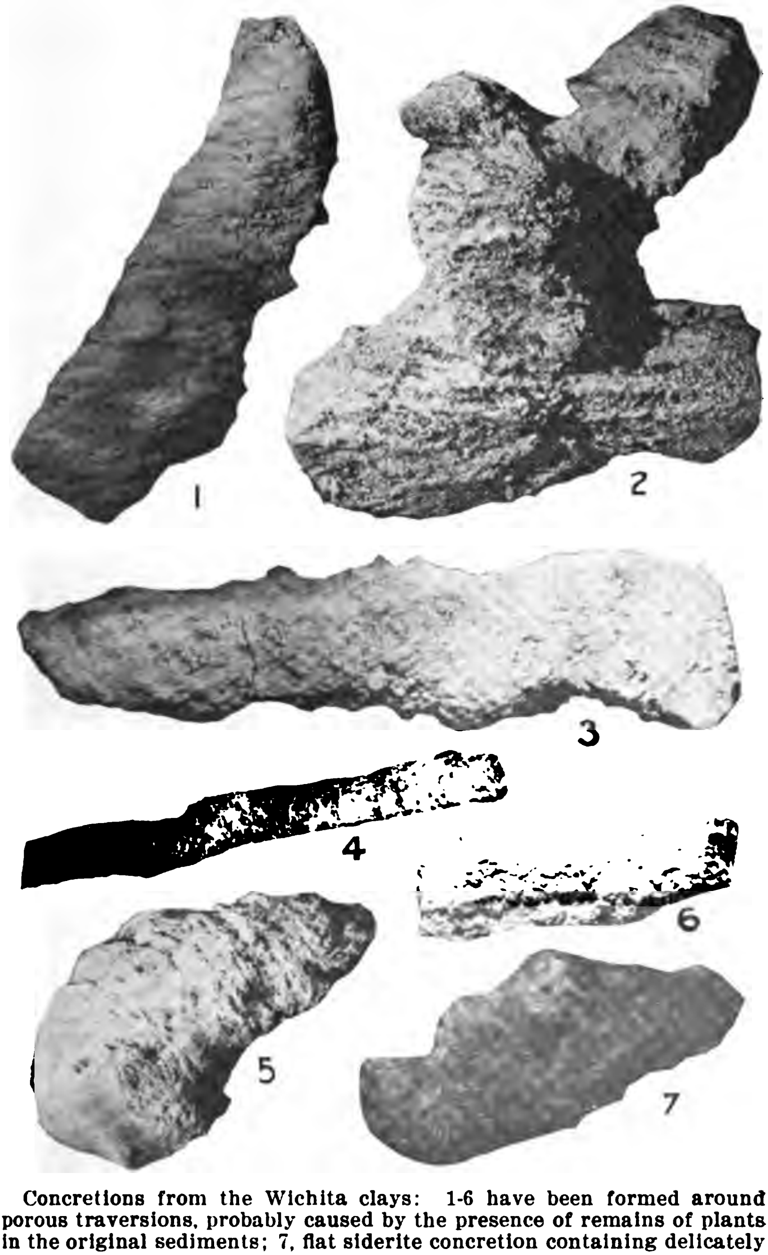
Concretions from the Wichita clays: 1-6, malachite concretions, slightly reduced; 7-11, double forms, calcareous; 8, 9, interlocking growths, calcareous; 7, 10, 11, concretions showing stratification. Photographs by F. L. Whitney.



Concretions from the Wichita sandy shales and sandstones: 1-6, probably formed around vertical and slanting open traversions in sandy shale; 7-10, formed in sandstone. Photographs by F. L. Whitney.



Concretions from the Wichita clays and sandstones: 1, flat form with concentric structure; 2, transverse section of the same; 3, calcareous concretion with nucleus of gypsum; 4, showing shrinkage cracks; 5-7, showing cracks filled with ferruginous (5), gypseous (6), and calcareous (7) material; 7, 8, 9, showing original stratification. Photographs by F. L. Whitney.



Concretions from the Wichita clays: 1-6 have been formed around porous traversions, probably caused by the presence of remains of plants in the original sediments; 7, flat siderite concretion containing delicately preserved imprints of leaves. Reduced to one-fourth natural size. Photographs by F. L. Whitney.

tionary growth, and of a later resumption of the same, which has been more localized.

Internally the concretions in some cases show an irregular concentric structure, and in one locality this was seen to consist of numerous smooth and even concentric layers. More frequently they have radiating internal fissures which are filled by somewhat pure carbonate of lime, either in the form of crystalline calcite, of amorphous calcite or of a white powder of the same mineral. In other instances the internal structure shows that some concretions are aggregations of many concretions of smaller and greatly variable sizes. Photographs of many concretions from the clay are shown and described on Plates XVII, XVIII, XX, and XXI.

SANDSTONES.

The sandstones of the Wichita formation constitute something less than twenty per cent of the whole in the exposures. They are mostly light gray in color, though some are red, dark gray, or mottled.

The development of the sandstones is irregular. They frequently change in thickness and may run out in a few hundred feet. They can seldom be traced in continuous outcrop for more than a mile or two.

Texture.

The sandstones are fine in texture, about eighty-five per cent of the weight of the sand consisting of grains measuring from one-fourth to one-sixteenth of a millimeter in diameter. Grains measuring more than one-fourth of a millimeter are scarce, constituting only a small fraction of a per cent, in case any such grains are present at all. Compared with other sands the Wichita sands are well sorted. They contain very little material in which the grains measure less than one-sixteenth millimeter in diameter. In this respect the Wichita sand is a true beach sand. To plainly present these characteristics a few mechanical analyses have been made as shown on following page. Analyses of the three Cisco sands are also introduced for comparison.

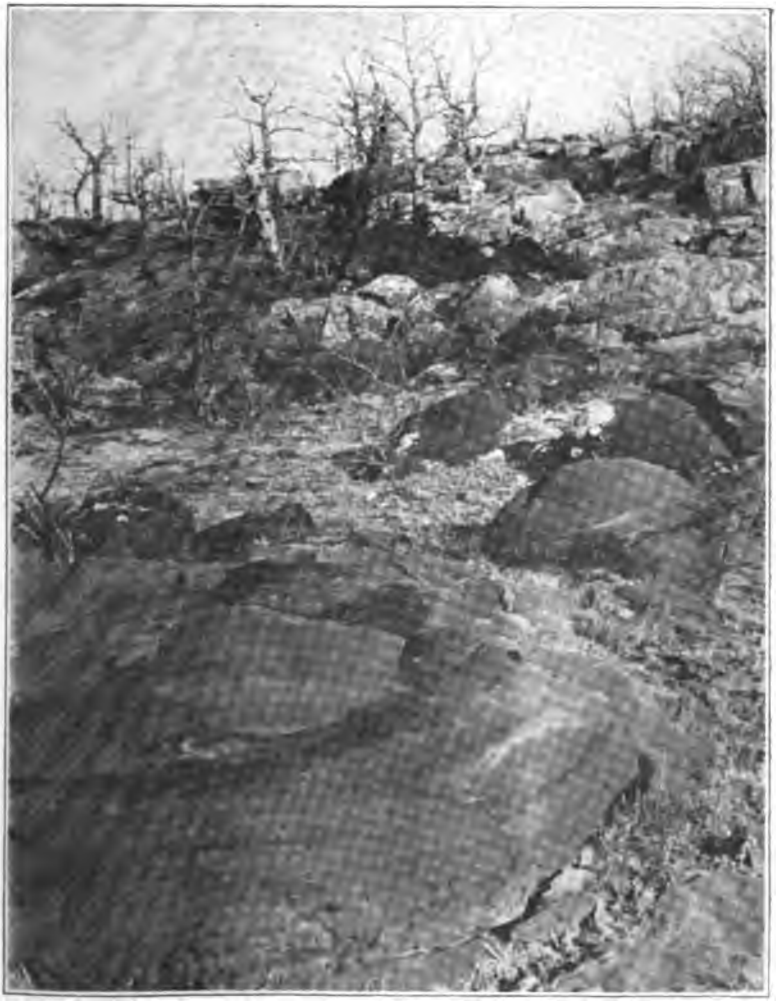
TABLE SHOWING THE MECHANICAL COMPOSITION OF SANDSTONES IN THE WICHITA AND THE CISCO FORMATIONS, IN PERCENTAGES OF WEIGHTS OF DIFFERENT GRADES OF COARSENESS.

Diameter of sand-grains in mm.	Cisco sands.				Wichita sands.						
	South of Bellevue, Clay Co.	Five miles east of Henrietta, Clay Co.	Near Bellevue, Clay Co.	Averages for Clay Co.	Finder's Butte, 8 miles W. N. W. of Holliday, Wichita Co.	Three miles west of Burkburnett, Wichita Co.	Wichita Falls, Wichita Co.	Butte on Palo Pinto School Lands, Wichita Co.	Tenth Cavalry Creek, Wichita Co.	Electra red sand, Wichita Co.	Average for Wichita County.
1—½	1	tr.	tr.	tr.	------	------	------	------	------	------	------
½—¼	20	8	tr.	9	------	------	------	tr.	------	------	tr.
¼—⅛	43	69	84	67	81	79	62	57	43	28	57
⅛—1/16	26	9	10	15	11	13	27	29	38	48	28
1/16—1/32	10	4	6	7	8	8	11	14	19	24	14
1/32—1/64	------	------	------	------	------	------	------	------	tr.	tr.	tr.

The Wichita sands do not appear to be greatly worn, for even the coarser grains are not well rounded. The surface of the sand grains very generally shows the effects of etching, being roughened, or very irregularly pitted. This etching has no doubt been effected by the solvent action of percolating ground water, which at times probably has contained a comparatively large amount of alkalies in solution.

Mineral Character.

The original mineral composition of the sand is more or less clear quartz, some chert, and some orthoclase, and mica. Mica scales are present, but usually very scarce. They are most frequently to be seen in thin-bedded, silty strata of the rock, where they appear most copiously in some seams of the foliated rock. The orthoclase is of a pink color and constitutes probably no more than one per cent of the rock. The relative quantity of chert is difficult to estimate. This constituent consists of grains which are opaque, and either white, yellow, dark gray, or even red, but there is also yellow and red material which is not chert. Some thin sandstones, that merge into limestones, horizontally, contain organic and calcareous fragments which, in rare cases, constitute a large part of the rock material.



Large concretions impregnated with manganese and iron. In a sandstone escarpment in the southeast bank of the West Fork of Trinity River, Archer County.

Secondary Minerals.

Much of the Wichita formation sandstone contains minerals which have been introduced secondarily. The most conspicuous of these are calcite, hematite, limonite, wad, malachite and azurite.

The copper minerals are almost always found impregnating sandstones only in association with plant remains, lodged in beds of shale contiguous to the sandstones. They also appear very sparingly, but persistently, in the thin calcareous and organic sandstones which were seen replacing the limestones horizontally.

The wad is known by its characteristic black color, and is more or less local and concretionary. It has evidently been introduced in the sandstones interstitially by the ground water and was probably derived from the clays of the formation. In some finely stratified sand it impregnates only some of the thin layers and not the others, giving a trenchant expression to the lamination of the rock. In some sandstone strata that occur in outcrops at Petrolia and in the uplands between Wichita Falls and Jolly, the wad has gathered in large flat and round concretion-like parts of the rock which measure up to several feet in diameter, and in some places it has impregnated strata of the sandstone a foot thick for several yards length in the exposures. See Plate XXII for similar concretions as found in Archer County. In the roads east of Petrolia some mill-stone-size concretionary impregnations of wad in the sandstones are disintegrating more rapidly than the mass of the rock, and this causes some peculiar round and shallow hollows in the road bed. In two instances some radiating impregnations of wad were noted. which illustrated the dendritic habit of this mineral.

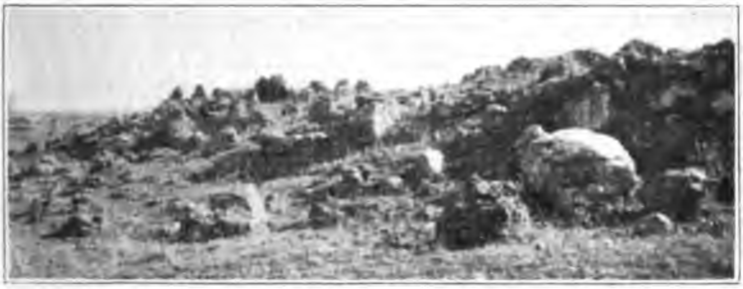
The ferruginous minerals give the red color noted in some sandstone. It is significant that the red color is most common in the sandstones which have the smallest development. It is specially persistent in a sandstone which is interbedded with red shale in the upper part of the section at Electra. The heavier sandstones of most constant development are more generally gray or white. This suggests that where the ground water has circulated most freely these minerals have not been as frequently deposited as in the strata where the solutions have been more effectively confined.

Calcite is present as an introduced material in much of the sandstone. At least a trace of it is present in nearly all sandstones as a more or less effective cementing matrix. Like the wad, it is in some places present in certain layers and seams in greater quantity than in others, and like the wad it has in some places collected into large concretionary forms. These have weathered out and rise as mildly grotesque protuberances from the ground in places where the softer and less effectively cemented main body of such sandstones has been removed by erosion. See Plate XXIII, A and B. In a few instances smaller symmetrical calcareous concretions were noted in the sandstones. These are more frequent in the lower sandstones exposed in Clay County than in the higher sandstones exposed in Wichita County. Plates XIX and XX show various forms of concretions in sandstones.

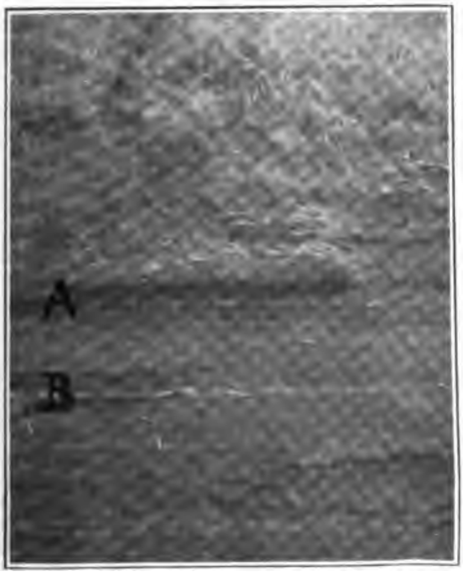
Characteristic Bedding in Sandstones.

We have already noted that in their mechanical composition the Wichita sandstones resemble beach sands, or near-shore sands, being well sorted. Physical conditions of this kind are also indicated by other features of sedimentation. In a few places the sandstone is a freestone, showing no preferential planes of cleavage in any direction, and no bedding planes of any kind. But no strata of this kind were noted exceeding four or five feet, nor did these appear to run far horizontally. It suggests itself that such beds may once have been small wind drifts on the sandy beaches, which happened to remain undestroyed and to be buried under other sands later brought by the coastal currents of the sea. Usually these sandstones are distinctly stratified and are built in layers from a few inches to a foot or two thick. Sometimes these layers show a fine horizontal lamination. There extend smooth and straight division planes horizontally in the stone for many yards in both dimensions of a horizontal plane. These divide the layers into thin laminae from a sixteenth to a fourth of an inch thick. Even the thinnest of these laminae seem to be traceable for many feet, and with favorable weathering slabs of

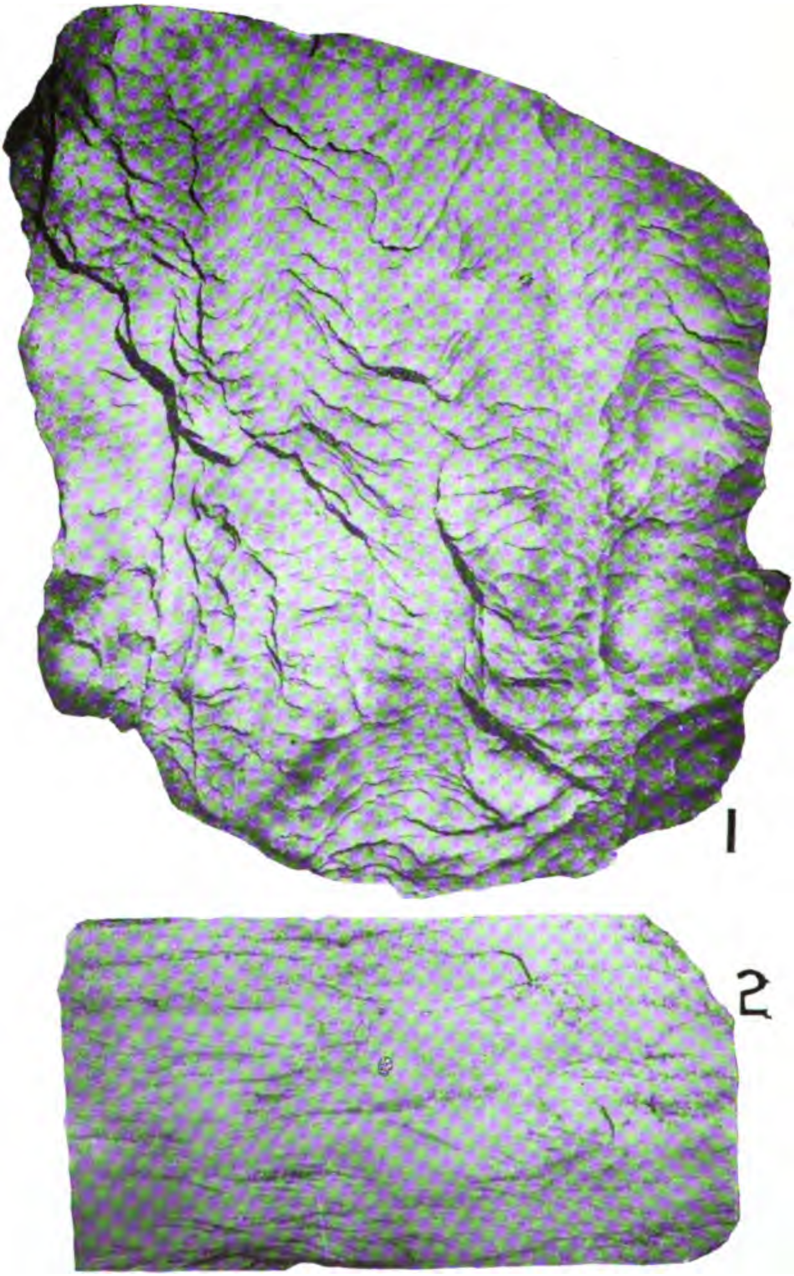
A. Concretionary Wichita sandstone near the nortnwest corner of Survey 16, W. W. Carroll, about four miles southeast of Electra, Wichita County. Looking northeast.



B. Concretionary Wichita sandstone near the south bank of China Creek about 2 miles above its mouth. Looking east. I. J. Broman.



C. Red shales (Triassic?) in the bank of Duck Creek on the Spur Ranch in Dickens County. A. and B. are two wavy layers of clay. These are at regular intervals alternately light gray and red in color. The texture is apparently identical throughout these layers. The white color is developed mostly in the wavy slants to the right in the plate. Another layer, resting on B, shows inclined streaks of white on the right side of each wave. This layer is not cross-bedded. W .E. Wrather.



Characteristic bedding of Wichita sandstone. 1. View parallel with bedding plane. 2. View of vertical section. Photographs by F. L. Whitney.

such rock may be split into plates not much thicker than a card-board and as large as a man's hand. In places these thin layers are marked by parallel varicose lines, which seem to be wave marks. In other places the division planes are themselves thrown into very shallow, hardly perceptible folds a few inches wide. These are evidently incipient ripple marks, for in some places they are found in association with well developed ripples. Ripple marks are not very common features in the bedding of these sands, and were noted at only a few places in this field. See Plate XXIV, 1.

Cross-Bedding.

The most frequent and conspicuous bedding characteristic of the Wichita sand-stones is cross-bedding or so-called false bedding. There are few outcrops of sandstone where this form of stratification may not be found. The thinness of the beds in this field prevents it from being developed on a grand scale. The thickest single cross-bedded strata noted here are not more than three feet in thickness, and the common thickness of single layers of this kind is less than one foot. On the other hand, the development of small, fine work in cross-bedding seems to have reached a culmination in these sands. Layers no more than a half inch thick are often seen to be quite regularly cross-bedded. See Plate XXIV, 2. It is evident that this cross-bedding is the result of currents in the direction of the slant of the false bedding. These slants are, in each case, the indices of local currents which produce them. In each outcrop there may often be found several directions of these slants, but usually one or two directions prevail. For the purpose of securing some information on the general direction of the transporting currents which brought this sand, some observations were made on the direction of the slants in the false bedding of the thickest strata. Each slant noted was referred to one of eight directions of the compass, the four cardinal points and the four intermediate points. In all, 125 observations were taken, thirty in Clay County and ninety-five in Wichita County. Tabulating the recorded data we find them as follows:

TABLE SHOWING THE DISTRIBUTION TO EIGHT POINTS OF THE COMPASS OF THE DIRECTIONS OF SLANTS OF FALSE BEDDING IN THE SANDSTONES OF THE WICHITA FORMATION IN CLAY AND WICHITA COUNTIES.

Direction of the slants.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	All.
Number of slants in Clay County	8	1	2	2	1	7	5	4	30
Number of slants in Wichita County	17	2	7	7	10	13	29	10	95
Number of slants in both counties.	25	3	9	9	11	20	34	14	125

Plotting these directions, we find that the resultant for Clay County points about twenty-six degrees north of west, and for Wichita County, about two degrees north of west. All the observations combined make the resultant direction seven degrees north of west. See fig. 5.

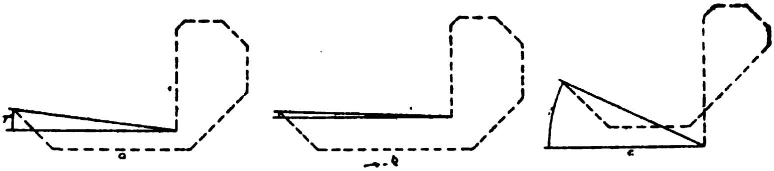
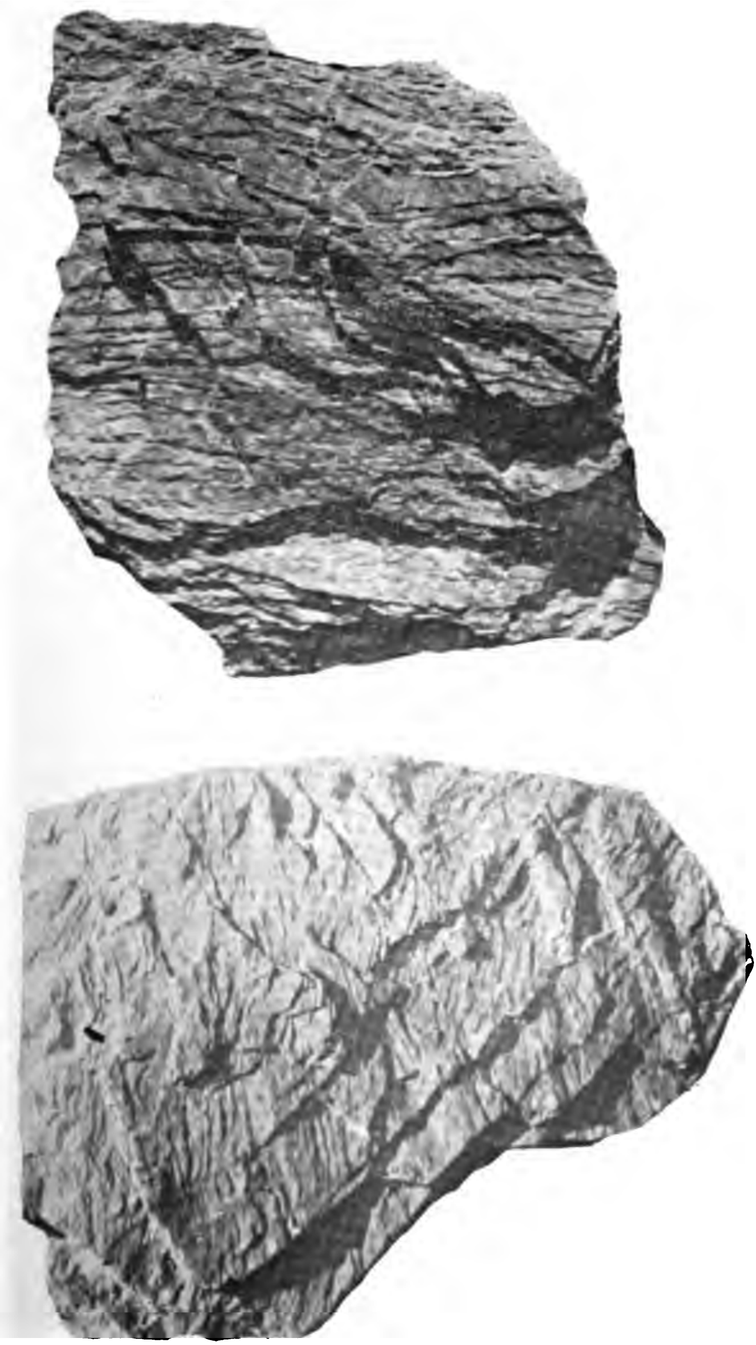


FIG. 5. Resultants of directions of slants in cross-bedding: a, resultant of 125 observations in Clay and Wichita Counties; b, resultant of 95 observations in Wichita County; c, resultant of 30 observations in Clay County.

Significance of Cross-Bedding.

The greater frequency of the westwardly directed depositing currents is clearly shown by these observations. It would nevertheless be hasty to conclude that the resultant direction is a true index of the direction from the land to the sea at the time of the making of these beds. The general direction of transportation in sand bars and sand beaches is not always from the land seaward. It may as well be parallel with the coastline. But it can not be largely from the sea landward. All that we may safely infer from these observations is that the land at that time was not to the west with the sea to the east. If the ancient shoreline extended in a north and south direction, there must have been an open sea to the west. But if the course of the shoreline was from east to west, the land may, so far as these observations are concerned, have been somewhere in a northeast, or an east direction. The northward trend of the resultants renders it unlikely that the shore line extended in an east-west course, as this would require a landward transportation of the sand.

Plate XXV.



Slabs of sandstone showing faults produced by settling in unindurated sediments. Photographs by F. L. Whitney.

The land hence probably lay to the east, southeast or northeast, all evidence considered, with the open sea to the west, northwest or to the southwest.

Small Contemporaneous Faulting.

Some thin and fine-grained layers of sandstone which are interbedded in the red shales in the brakes of Bluff Creek southwest of Electra, exhibit a peculiar small faulting, which is believed to have taken place almost immediately after the sand was laid down, and before it had become consolidated to any degree. See Plate XXV. Layers of sandstone one to four inches thick are faulted along gently but somewhat irregularly curving lines, which run roughly parallel from a half inch to several inches apart. The displacement at each little fault is from zero to a half inch. We have seen such faulting in rapidly accumulated soft mud settling on sloping banks under its own weight, and we have no doubt but that these structures have a similar origin. Their presence in these beds indicate that sedimentation was rapid. In some sands belonging in about the same horizon and in the same part of the field, were also to be seen some vertical or slightly oblique perforations more or less perfect, seldom more than an eighth of an inch in diameter. These are probably either worm borings of some kind or cavities left by imbedded plant structures.

Some Larger Bedding Structures.

The fact has been mentioned that the sandstone beds can not with certainty be traced for any considerable distance. They disappear, frequently, in less than a mile. Instances of this kind have been referred to in some of the described sections, as in sections 10, 16, 20, 22, and 24. See also Plate XV. Another case of this kind was noted at a point about three miles east of Wichita Falls, where the main wagon road turns up in the low bluff. A silty sand, with a dip that is evidently incidental to the bedding, terminates against a sloping clay surface. The outcrop is somewhat obscure. Other cases of dipping sandstones, where the dip is evidently original in the bedding, were noted in survey 27, H. & T. C. R. R. Co., about six miles south and two miles west of Electra. At this point a sandstone runs some 150 yards with a dip of several degrees to the east, but on all sides of this place the formation lies horizontal. Another dip of this kind was noted in the ravines about two miles south and one mile west of Electra. In a hill facing northeast near the east line of the W. W. Carroll survey, some five and one-half miles north and four miles east of Iowa Park, some layers of sandstone, interbedded with red shale, dip some ten to fifteen degrees to south and disappear from the outcrop. Close to the south the overlying red shale is capped by some thin gnarly black limestone, and this lies horizontal. In all of these cases we believe that the dip is original in the bedding, and in several cases the evidence is clear that an excavation has been made in the accumulating clay and sands, and the dipping beds have been laid down on the sloping sides of the excavation. We believe that these excavations may very well have been made by bottom currents in littoral waters, for there are no evidences of weathering or decay along the contacts on the bevelled layers. See Plate XV, A. It is well known that sand banks on the gulf coast are continually undergoing changes, and excavations of several feet may be made more or less extensive in the course of a year. Tidal currents are especially effective in such work. The universal occurrence of cross-bedding in these sandstones, and perhaps also the frequent presence of extensive flat and thin lamination which we have described, may perhaps be regarded as additional evidence of tidal action. We believe that these sandstones were originally mostly submerged sandbars and in some cases sandy beaches. Wave marks, marks of rain drops and rill marks are not often to be seen. It appears to us that these should be more frequent, if the greater part of these sands were emerged beach sands.

Fossil Plants.

The only fossils noted in the sandstones were a few impressions of leaves and some problematic structures which may be impressions of some form of vegetation. The leaves have been examined by David White, who has kindly furnished the following identifications and notes:

1. Pecopteris, a fragment not specifically determinable, on account of obliteration of the nervation.
2. Taeniopteris, several fragments, indistinct as to nervation.

3. **Gigantopteris, two or three pieces, one of which is a gigantic overgrown Callipteroid type such as has not been known outside of the Uralian Permian.**

Though taken from points several miles apart, it is believed that these leaf impressions come from one and the same horizon, a horizon which seems to be the stratigraphic equivalent of a calcareous bed elsewhere containing vertebrate remains. In the sandstones containing these leaf imprints, the vertical perforations already noted are frequently to be found.

CONGLOMERATES.

In all the sandstones examined in Wichita County and in the northwest quadrant of Clay County no quartz grain or pebble was noted which was more than a millimeter in diameter. Coarse ingredients from the same source as the bulk of the sand have been effectively left behind by the currents transporting the sand. Nevertheless some coarse sediments were found together with the sands and the shale, but these are, as we might say, of indigenous origin, and have not been transported from the same places as the rest of the material in the sands and the shales. These indigenous coarse sediments may be designated as bone breccias and mud-lump conglomerates. We shall describe the bone breccias in connection with the limestones, of which they make a somewhat rare feature. The conglomerate has been noted by all earlier observers in this field. Mr. W. F. Cummins very aptly referred to it as "a peculiar conglomerate." It occurs in most frequent association with sand, quite often appearing as a basal layer under sandstone. Quite frequently it forms separate layers interbedded in sandstone. In the described sections it occurs interbedded in sand in eight cases and underlies sandstone and overlies shale in three instances. In four instances it was found interbedded in shale, which at least in one case was slightly sandy and stratified. The assertion appears to be warranted that the associations of this conglomerate indicate its formation in situations where currents in the depositing waters were active. The conglomerate consists of more or less rounded bodies of indurated and compact calcareous and argillaceous material. Some of these are calcareous, others argillaceous or ochreous. They measure from the size of sand grains to an inch and a half in diameter. Many exhibit an obscure concentric structure, which is most apparent near the periphery. Many have internal fissures such as characterize clay-ironstone concretions and calcareous concretions in clay beds. These balls, as we may call them, are more or less uniform in size for different beds, having evidently been sorted by the transporting currents. In the coarsest conglomerates noted they perhaps average half an inch in diameter, and in the conglomerate of finest texture the individual pebbles averaged less than one-tenth of an inch in diameter. Balls of the size of a pea are common in samples where the sorting has been most perfect. These balls or pebbles are imbedded in a matrix of clay or of sand, or of a mixture of these. The matrix may be only a filling in the interstitial spaces in the conglomerate, but it constitutes more than one-half of the rock. In some localities the conglomerate has evidently suffered alteration from mineralized ground water, in places substituting copper carbonate, ochre or wad for the calcareous ingredients in the rock and in places merely precipitating these minerals in the original matrix.

Conglomerates like this are indeed not unknown in other formations consisting largely of clay and shale. They have been noted by one of the present authors in the late Cretaceous clays in Brewster County in Texas and in the Pennsylvanian in Illinois and in Iowa. In Ohio a somewhat similar rock has been noted and described as a "dessiccation conglomerate."[1] In his paper on "The Physical Origin of Certain Conglomerates,"[2] J. H. Gardner shows how water currents which are overloaded with fine mud will form balls which resemble concretions, and Wm. B. Phillips[3] has described how balls of fine clay are formed in the troughs of the log washers in the treatment of brown ores in Alabama. That most of the balls which make up these conglomerates have been formed by a process of rolling, appears likely from the concentric structure which many of them have. But some of the pebbles have evidently withstood more wear than mere mud

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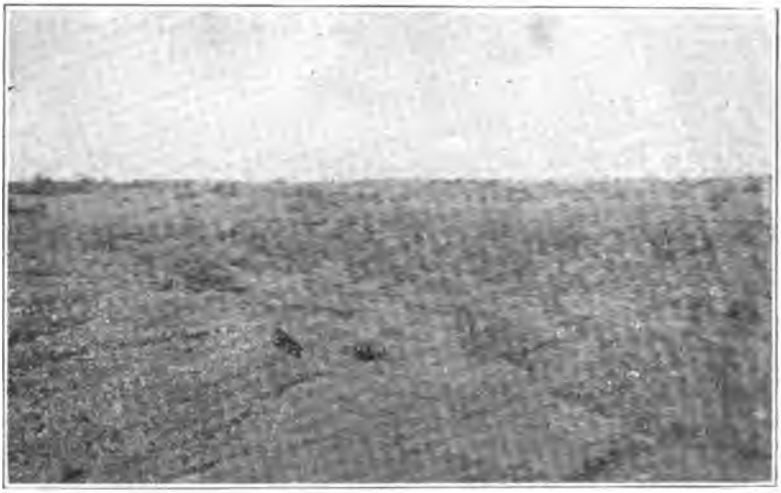
[1] J. E. Hyde, Am. Jour. Sci., Vol. XXV, 1908, p. 400.

[2] Journal of Geology, Vol. XVI, p. 452.

[3] Iron Making in Alabama, Alabama Geological Survey, Second Edition, p. 55.



A. The Beaverburk limestone on the H. & T. C. Ry. Survey 33, 8 miles south and 1 mile east of Electra, Wichita County. The limestone blocks are slowly creeping down on the slope from the edge of the hill. This is nearly on a level with the photographic eye. Looking northeast.

B. A sandstone containing small calcareous concretions, originally imbedded in the sand. Erosion has exposed a layer in which the concretions are fairly abundant. These still adhere to the rock, or are only partially laid bare. About 4 miles south of Electra, Wichita County. Looking southeast.

balls can do. These must have been considerably indurated originally, and they have the appearance of being true calcareous concretions. It is believed that such pebbles in the conglomerates may have been washed out from clays in which they first were formed by true concretionary growth. The frequent association of sandstone and of these conglomerates with contemporaneous unconformities or local excavations in the clays, is significant in this connection. It is known that concretionary growths may form quite rapidly, and on the gulf coast places may now be found where the waves are beating down banks of recently formed clay, leaving thin layers of calcareous concretions mingled with sand on the beach at the foot of the clay cliff. A sandy conglomerate of such concretions, that perhaps was laid down on a beach in this manner, was noted in the breaks about four miles south of Electra. The concretions have evidently been imbedded in the upper surface of a stratum of sand to which they adhere in the exposure. See plate XXVI, B. The absence of everything but indigenous material in conglomerates which clearly have been produced by currents of considerable strength, suggests isolation of the coasts from mountain lands, while the Wichita beds of this region were deposited. The underlying beds of the Cisco formation contain pebbles of chert and of granite, which are derived from the Wichita Mountain uplift. Evidently the geographic conditions prevailing during the deposition of the Wichita beds were different from those existing during the making of the Cisco beds.

THE BEAVERBURK LIMESTONE.

While the clays and the sandstones of the Wichita formation are too irregular in their development to be individually correlated, at least one limestone was found which it was possible to follow for a dozen miles or more, even though it may not be quite continuous for this distance. We have called this the Beaverburk limestone, for the reason that it is well developed in the basin of Beaver Creek, and has been traced northeast as far as to Burk Station on the Fort Worth and Denver Railroad.

This limestone caps the upland bluffs on the north side of the Wichita River in the southwest corner of Wichita County, where it has its greatest thickness and measures about three feet. Its outcrops have been traced from this point northeastward across the basin of Beaver Creek, and from there northward and eastward to Burk Station, as indicated on the accompanying map. In the Beaver Creek basin the rock is less than two feet thick, and in some places less than one foot. Northeast from the Beaver Creek basin, and in the vicinity of Burk it is less than six inches thick and is evidently not always present in the section. The horizon where it belongs is, however, marked by a continuation of the dark or greenish-gray shale which underlies. This shale is traceable eastward as far as to the hills two miles northwest of Iowa Park. A thin shell of limestone, which may be a continuation of this limestone, was noted at a point on a hillside three miles north and one and one-half miles east of Iowa Park.

List of Localities of the Beaverburk Limestone.

1. On the north side of the Wichita River in the west part of the L. T. Miller survey 28, five miles above the mouth of Beaver Creek, this limestone caps the river bluff. It is two and one-half feet thick and is overlain by some dark clay, which contains several thin shells of dark limestone like that below.

2. On the H. & T. C. R. R. survey 25, and on the adjoining Childon survey 26, from nine to eleven miles south and a mile east of Electra, are several outcrops in the heads of the ravines, and the rock averages from ten to eighteen inches thick.

3. In the bank of Beaver Creek at the Guthrie Ranch bridge, in the northeast corner of the Bynum survey 22, the limestone outcrops at the north abutment of the bridge. I [illegible] sts on the usual dark greenish-gray shale.

4. In the breaks of Beaver Creek in the west half of the H. & T. C. R. R. Co. survey 33, about four and a half miles west of the mouth of Beaver Creek, and on its north side, the limestone outcrops extensively. It measures from a foot, or less, to eighteen inches thick. In many places there are a few inches of clay above the main limestone, and then there is a three to four-inch layer of limestone. This contains a Syringopora, in some places in profusion, and some minute gastropod.

5. In the tributary to Beaver Creek running south through the H. & T. C. R. R. Co. survey 35, about seven miles south and

three miles east of Electra, the limestone outcrops on both sides of the creek for a distance of a mile and a half. It is from six to eighteen inches thick, and the upper four inches contain Syringopora in many places.

6. In the north part of the Lamphear survey 2, five and a half miles west and one and one-half miles south of Burk, the limestone rests on dark gray clay and is from four inches to a foot thick.

7. On the slopes of the shallow ravines in the north part of the H. & T. C. R. R. Co. survey 1, about five and one-half miles west of Burk, the limestone is six inches thick and rests on bluish-gray shale.

8. In the south half of the S. B. Burnet survey 12, about four miles west of Burk, the limestone is some four inches thick and crops out in a shallow ravine.

9. On the north side of the main wagon road, about one-fourth of a mile west of Burk, the limestone is a thin shell some three inches thick or less, black and slightly bituminous. It can be traced on the surface a half mile to the east and a short distance to the northwest, and was seen to contain a Syringopora, *Estheria minuta* Jones, and occasional fish scales.

This limestone is mostly a tough dark gray rock, that effectively withstands weathering. It has been used very generally for building stone and in foundations at the neighboring ranches. It breaks along two main systems of joints into rectangular and sometimes diamond shaped blocks, often in sizes small enough to be handled and hauled away. Where the limestone caps a small slope these blocks creep down on its surface, forming a pavement in which the blocks maintain their arrangement in rows for some distance down the slope. This is frequently seen in the breaks on the H. & T. C. R. R. Co. survey 33. See Plate XXVI, A.

Chemical Composition.

Two chemical analyses have been made of this rock by Mr. S. H. Worrell. One of the samples analyzed (1) was collected in the H. & T. C. R. R. Co. survey 33, where the rock has a moderate development for this region, and the other sample (2) is from the vanishing northeast edge of this limestone, where the rock is only three inches thick. It will be noticed that the rock at these two places is very similar in composition, the contents of silica, alumina, oxide of iron, and lime varying but little. The manganese is no doubt a secondary mineral, introduced after the rock was made in the Burk locality. The considerable variation in magnesia may also be the result of secondary local changes. The greater quantity of organic matter in the sample from the north locality is evidently an original difference, as the rocks in this locality show more of organic structure in their texture. These analyses are as below:

Analyses of the Beaverburk Limestone.

1.

	Per cent.
Silica	7.56
Alumina	14.93
Oxide of iron	2.57
Lime	35.74
Magnesia	5.69
Sulphuric acid	0.65
Carbonic acid	33.80
Phosphorus	trace
Water	none
	100.94

2.

	Per cent.
Silica	8.81
Alumina	12.74
Oxide of iron	2.40
Lime	35.14
Magnesia	1.12
Oxide of manganese	3.05
Sulphuric acid	trace
Carbonic acid	34.74
Phosphorus	trace
Alkalies	0.37
Moisture	0.22
Organic matter (by difference)	1.41
	100.00

In its original form the rock is almost compact and structureless, save for the presence of more or less obscure lamination. Under the microscope the sample (1) in the above analyses exhibited an exceedingly fine and homogeneous granular texture, the granules being somewhere near one thousandth of a millimeter in diameter and appearing like the crystals in a fine textured dolomite. In the granular matrix various curving lines were noted, some of which were very thin imbedded small bivalve shells. Several thin sections, cut in three dimensions vertical to each other, of the rock near Burk, consist largely of a tangle of irregularly bending and branching laminate structures, about one twentieth of a millimeter thick. These lie mostly flat with the bedding planes and enmesh a varyingly copious matrix, consisting in part of structureless material and in part of small lump-shaped bodies of lime. There are also various shell fragments, and irregularly shaped impregnations of black bituminous material, scattered through the mass. The structure of the rock suggests that it has been formed, at this point, to some extent from a multitude of thin shells encrusted with lime, which became imbedded in a calcareous precipitate mixed with some fine clay. In the Beaver Creek basin and along Wichita River the rock is in many places somewhat porous, and has a dark brown rusty color. These are evidently secondary characteristics, due to solution and infiltration by the ground water. Irregular pockets filled with crystalline calcite must be ascribed to the same cause.

Fossils of the Beaverburk Limestone.

Aside from the probable fragments of ostracod shells appearing in thin sections of this limestone, only one fossil is fairly abundant. This is a Syringopora consisting of free tubes, circular in cross section, and having external transverse lines of growth. This fossil is fairly abundant in the upper six inches of the limestone in the south part of Wichita County, and no outcrop was noted anywhere in which it was entirely absent. Some places were noted where the coral filled the rock, having grown in colonies a foot wide and from three to four inches high, the tubes frequently being in contact with each other and spreading gently from below upward. A list of all the fossils noted is as below:

	Locality.
Syringopora, sp	In all outcrops.
Myalina, sp	Beaver Creek bluff, four miles above mouth of creek.
A small gastropod	Beaver Creek Bluff. four miles above mouth of creek.
Estheria minuta Jones	Burk.
Fish scales	Burk.

THE BLUFF BONE-BED.

On both sides of Bluff Creek, south of Electra, there is a calcareous bed, or horizon, which in many places caps a bench on either side of the creek. It is most often seen on the west side of the creek, and was traced from a point on the Jno. W. Carter survey 24, half a mile north of the place where Beaver Creek is crossed by the west boundary of Wichita County, to near the center of the H. & T. C. R. R. Co. survey 19, about five miles southwest of Electra, a distance of five miles. Scattered localities of what is either known or believed to be the same horizon were seen in the breaks on the east side of Bluff Creek in a belt about one mile east of the west boundary of Wichita County, and parallel with this, extending from a mile north of Beaver Creek to a point west of Electra. It was also noted in a low bluff or terrace extending from a point a mile south of Electra eastward for three miles on the south side of the headwaters of Buffalo Head Creek, at scattering points in a belt extending three miles east of Electra, and again in the basin of China Creek nearly two miles north of Electra.

List of Localities of the Bluff Bone-Bed.

The details of the observations in these localities may profitably be recorded. They are as follows:

1. A low terrace-like shelf follows the south side of the principal creek draining eastward in the north part of the J. A. Roesh survey, one and one-half miles south of Electra. This is capped by a thin shell of rock consisting of sand, fragments of fish scales and bones, and rolled lumps of marly clay, all imbedded in a matrix of lime and ochreous material. Some eight-inch long spine-like saurian bones were noted and also casts of *Estheria minuta* Jones.

2. On a low hill east of a water tank which is near the west boundary of Wichita County, about two-thirds of a mile north of Beaver Creek, there are remnants of a thin shell of rock, which consists of a compact mixture of rolled calcareous lumps from one-tenth of an inch to half an inch in diameter, fragments of bones and scales of fish, imbedded in a matrix of granular calcareous material, which in some places is crystalline.

3. On a low terrace-like shelf cn both sides of Bluff Creek, near the west boundary of Wichita County, and from one-half to one and one-half miles south of Beaver Creek, the capping rock consists of different mixtures of sand, calcareous material, clay and fragments of bones and scales of fishes. There is at this place a stratum of very compact gray limestone, extending for some hundred paces, which contains numerous imbedded shells of an ostracod, probably *Paraparchites humerosus,* and many symetrically grown colonies of a Syringopora, one of which was seen to have begun its growth on a spiral shell (Bellerophon?), an impression of which is left in the base of the polyp colony. Small fragments of bones of vertebrates were also noted.

In a short distance this limestone is not seen any more, but we find at the same horizon a sandstone, which contains much calcareous material, scales of fishes, and many fragments of vertebrate bones.

At another place the horizon is marked by a conglomerate consisting of rolled lumps of calcareous and clayey material imbedded in a sandy matrix in which are also found small fragments of vertebrate bones and scales of fishes.

In all these places the rock containing the vertebrate remains rests on a few feet of blue shale, which again overlies red shale.

4. For some miles to the north of this locality, in the breaks of an irregular belt running parallel with the west boundary of Wichita County, and from one-half to one and a half miles east of this boundary, what is believed to be the horizon of this bone bed is marked by beds of calcareous gray sandstone and irregular beds of red sandstone, frequently showing some vertical perforations and occasionally containing impressions of leaves of ferns, as already described under the heading of sandstones. In most of these localities fragments of bones may be found, and in some, such fragments are fairly abundant. In two

places, a half mile apart and about three and one-half miles south of Electra, the bone fragments were evidently sorted to size and some were slightly worn, as by wave action. On an area of some twenty feet square we collected 42 apparently identical limb-bones of a Clepshydrops, and 17 more limb-bones of nearly the same shape and size, either of the same animal or of Diplocaulus, together with 25 skull bones of *Diplocaulus magnicornis* Cope, 23 pieces from the pectoral girdle and the skull of a Trimerorachis, and various bones of the jaws, the spinal column, and an interclavicle of the same animals. These were all of about the same size, ranging from half an inch to one inch in their largest dimensions. Only a few larger bones were noted of larger size in the same place. The calcareous material of the bone bed seems to be mostly represented by bands of concretions in these localities.

5. At a point near the center of survey 20, about three and one-half miles south and three miles west of Electra, is a limestone which is no doubt the equivalent of the one described on the east side of lower Bluff Creek. This limestone caps an upland bench facing east, having an elevation of some 50 feet above the bed of the creek. It is a dark gray rock, about a foot thick, consisting largely of comminuted shell fragments and imbedded shells of an ostracod like *Paraparchites humerosus* U. & B., and many poorly preserved specimens of other fossils which we have identified as follows:

	Number of specimens noted.
Syringopora, sp	12
Murchisonia, sp	6
Pleurotomaria, sp	6
Allorisma terminale Hall	15
Myalina aviculoides M. & W.	8
Temnocheilus winslovi M. & W.	17
Nautilus, like excentricus M. & H.	3
Bellerophon crassus M. & W.	30

6. In the southeast quarter of the H. & T. C. R. R. Co. survey 19, at a point about three miles south and three and a half miles west of Electra, a hill is covered by a six-inch shell of limestone which is freshly laid bare by erosion over half an acre of surface. This rock is in part a very fine grained light gray lime-

stone and in part an organic calcareous sandstone, consisting of angular grains firmly cemented by a matrix, which is partly crystalline showing continuous reflections along cleavage planes. This contains many small fragments of vertebrate bones and minute specks of malachite. *Paraparchites humerosus* U. & B. was seen to be abundant.

7. About a half mile northwest of the preceding locality (Number 6), a gray sandstone was seen containing several impressions of leaves of ferns. This shell of sandstone was only some three to six inches thick, and was interbedded in gray shale. One of these has been mentioned above and identified as a Gigantopteris by David White, who says it is a gigantic overgrown callipteroid type, such as has not before been known outside of the Uralian Permian.

8. In the breaks about one and one-fourth miles southwest of Electra, the horizon of the Bluff Bone Bed is apparently represented by a calcareous sandstone a few inches thick, which contains the usual fragments of bones and fish scales.

9. About a mile south of Electra a low flat on the south side of the principal drainage line is capped by a calcareous sandstone from three to six inches thick, no doubt representing the horizon of the Bluff Bone Bed. It becomes a seam of concretions in the exposures farther south and is discontinuous to the westward, where it seems to be represented by some thin sandstone layers. The most calcareous outcrops contain *Estheria minuta* Jones, sometimes in profusion, and in one place a poorly preserved *Myalina* (*swallovi?*) was noted. To the east-southeast this stratum can be traced for a mile and a half and was seen to contain in one place bony spines ten inches in length.

10. In the A. J. Shaw survey 16, about four and one-half miles east of Electra, a calcareous and sandy seam containing vertebrate bones could be traced for a considerable distance on the low slopes of the uplands. It is nowhere more than a few inches thick. In places it contains rolled lumps of calcareous material, concretions, and scales of fishes. A mile further west, and at about the same level, a thin shell rock was found which is a breccia of entire and broken fish scales, mostly from one-eighth of an inch to one-fourth of an inch in diameter. The scales are lodged in a matrix of hematite, calcite and sand. An analysis

made by S. H. Worrell shows that the breccia still contains three and one-half per cent of calcium phosphate.

11. The sandstone seen in some gullies on the north side of the main road about a mile east of Electra is believed to belong to this horizon. It contains impressions of the leaves of a Pecopteris and vertical perforations such as were noted in a sandstone associated with bone-bearing shale in a place four miles south of Electra.

12. At a point about one and one-half miles northeast of the railroad station at Electra, the north bank of a small tributary to China Creek is capped by a sandstone changing into a mud lump conglomerate containing many small fragments of bones. It is less than a foot thick and is part of a sandstone. This sandstone follows the south bank of China Creek for a half mile or more to the southwest and contains occasional scales of fishes and small fragments of bones.

The reason we regard the strata described at these localities as belonging to one horizon is in the first place that no exposures were noted where we found two such horizons overlying each other. There is also one feature which characterizes the rocks in all the localities: one can find in all these places scales of fishes and fragments of vertebrate bones. Furthermore, such observations on the dip of the terranes as it was possible to make show that the outcrops described are in the positions where the general structure of the terranes would place them, if they represent a single horizon.

It seems probable that the horizon represents the coastward featheredge of a limestone which thickens to the southwest and which merges eastward into shore deposits containing in some places wave-washed detritus of the fauna of the time, and at other places containing these and also occasional plant drift lodged in rapidly accumulating sand, while in still other places the calcareous deposition may be represented by merely a layer of concretionary material. This seems the more likely since the calcareous material is most abundant to the west and south and nowhere sufficient to form a true limestone shell in the north and east outcrops. It will be remembered that there was a similar change in the Beaverburk limestone, which has a thickness of three feet in the southwest corner of Wichita County and thins out to a mere shell which merges into a bone and scale bearing sand east of Burk Station, and north of Iowa Park. It is possible that some calcareous, scale and bone bearing layers seen near Wichita Falls and near the Red River bluffs north of Iowa Park are similar littoral equivalents of this limestone.

Fossils of the Bluff Bone-Bed.

Below is a list of the fossils noted in the Bluff bone bed. Localities are indicated by numbers referring to the localities described above. The vertebrates have been determined, some by S. W. Williston and some by R. L. Moodie. The plants have been determined by David White.

	Locality.
Pecopteris, sp. (several specimens)	4
Taeniopteris, sp	4
Gigantopteris, sp. (two specimens, one of which is said by White to be a gigantic overgrown Callipteroid type, such as has not been before known outside of the Uralian Permian)	11
Walchia, probably W. pinnaformis	11
Syringopora (profuse)	3
Murchisonia (seven specimens noted)	5
Pleurotomaria, sp. (six specimens)	5
Allorisma terminale Hall (many specimens)	5
Myalina aviculoides M. and W?	5
Myalina swallovi McChesney?	9
Temnocheilus winslovi M. & W. (seventeen)	5
Nautilus, like excentricus M. & W. (three)	5
Bellerophon crassus M. & W. (thirty)	5
Bellerophon, sp	3
Estheria minuta Jones (profuse)	1, 9
Paraparchites humerosus U. & B. (profuse)	3, 6
Scales of fish, and teeth	Everywhere
Diadectes, sp. (a toe bone and many vertebrae)	4
Naosaurus, sp. (spines)	1
Eryops, sp. (vertebrae, skull bones, interclavicle)	4
Dimetrodon, sp. (parts of a tibia and a mandible)	4
Trimerorachis, sp. (intercentra, pieces of skull, jaw, and bone of the pectoral girdle)	4
Diplocaulus, sp. (skull bones and bones of the pectoral girdle)	4
Clepshydrops, sp. (limb bones, many)	4
Diplocaulus, sp. (limb bones and an interclavicle)	4

GENERAL SECTION OF THE OUTCROPPING ROCKS.

Reviewing all the observations made on the outcropping rocks, it is to be noted that less than one-half of all the localities described can with certainty be referred to their proper position in a general section. The Beaverburk limestone and the Bluff bone bed are the only identifiable units in the field. Of these the Beaverburk limestone does not extend eastward beyond Iowa Park, and the Bluff bone bed is not known to extend farther than four miles east of Electra. Only in one place were the field conditions such that a measurement could be made of the vertical distance between these two key-rocks. This is near the Webb well, just west of the west boundary of Wichita County, four and one-half miles south of Electra. At this place a shallow well has recently been made and a thin limestone, readily identified from fragments as the Beaverburk limestone, has been penetrated at the depth of about forty-five feet. In the low upland near this well the Bluff bone bed lies twenty feet above the curb of the well, so that the distance between these two members in our section is sixty-five feet at this place, as shown in Section 30. above.

The beds above the Bluff bone bed are shown in Sections 27 and 28, above, and consist of thirty feet of red clay overlain by some few feet of sandstone. This clay is also exposed north of the railroad a half mile east of Electra, and in the low bluffs around the artificial lake a mile west of Electra, as well as in the breaks on the east side of Bluff Creek.

About midway between the two key-rocks there is at one place on Bluff Creek a dark bluish-gray or almost black shale, only two feet thick, in which occur some flat clay-iron concretions as large as a hand. See Plate XXI, 7. These, as well as the shale itself, contain fragments of leaves in which the vegetable structure is unusually well preserved.

The sediments below the Beaverburk limestone are seen in several places in a belt about five miles wide, following the north side of the Wichita, from Burk Station southwestward. Such are the strata designated and described as 1, 2, 3 in Section 21; 1, 2, 3, in Section 26: 1 in Section 27: and 1, 2, in Section 28. But in none of these places are there more than 30 feet exposed of the beds below the limestones. Section 25, which is in the north bluff of the Wichita River, shows the thickest single exposure in the region and exhibits 125 feet of the sediments underlying the Beaverburk limestone. In all of these localities there are a few feet of sandstone at from twenty-five to thirty feet below the limestone, and in the deep section on the Wichita River just mentioned, there are four such beds of sandstone, approximately equal distances apart in the lower 125 feet seen. The whole succession of beds which it has so far been possible to construct from exposures is, therefore, as below:

SECTION OF THE WICHITA BEDS KNOWN FROM EXPOSURES.

	Thickness in feet.
Shales above the Bluff bone bed	32
Bluff bone bed	0-5
Shales between the Bluff bone bed and the Beaverburk limestone	65
Beaverburk limestone	0-3
Shales and sands below the Beaverburk limestone	125
	222-230

It is possible that some of the beds described in the east half of Wichita County and in the northwest part of Clay County are to be correlated with some part of the above general section, but it does not seem that such correlation can be made in the usual way. There seem to be no identifiable horizons in this part of the field, so far as yet examined.

STRUCTURE SHOWN IN OUTCROPS.

STRUCTURE AS SEEN IN KEY-ROCKS.

The course of the outcrops of the Beaverburk limestone shows that along this line there is no considerable dip. It maintains an elevation of about 100 to 140 feet above the Wichita River. It has a small dip to the south, north of Beaver Creek. South of Beaver Creek it is essentially horizontal. South-southwest from Electra, as far down as close to Beaver Creek, the Bluff bone bed has a dip of some fifteen to twenty feet to the south. But this dip probably does not reach farther north than to within a mile or two south of Electra. The same bed is seen to lie essentially horizontal along China Creek, which runs from southwest to northeast through the Electra oil field. This horizon is found at about the same level a mile south and again a mile east of Electra. But these are the only structural features that could be satisfactorily made out in the usual way from direct observations on traceable units of the section. The gross attitude of the terranes west of Iowa Park can be said to be horizontal on an east and west line.

STRUCTURE INFERRED FROM DIPS.

As it seemed highly desirable to ascertain the relative position in the general section of the fuel bearing sands at Petrolia and those at Electra, recourse was taken to a rather unusual expedient in the study of dips of flat lying formations . Notes were made on the attitude of the beds wherever opportunity offered itself, for any distance it was found practicable, and by any method available. Use was made of a common hand level for these observations, and in some places use was made of the aneroid. In all 116 observations were made on dips in promiscuous localities over the north half of Clay County, most of Wichita County, and in a few places in the east part of Wilbarger County. These observations were as detailed in the following list, arranged in order from west to east.

LIST OF DIPS.

Wilbarger County.

1. A limestone shell lies fifty feet higher at a point five miles west and one mile south of Electra, than at a point five miles south and two miles west of Electra. This makes a dip to the southeast of fifty feet in about four and one-half miles.
2. In the hills west of Bluff Creek in survey 20, three miles south and two miles west of Electra, a general south dip of about fifteen feet to the mile was noted.
3. Near N. R. Keim's ranch in survey 22, about five miles south and two and a half miles west of Electra, a dip of ten feet in one-half mile to the southwest was noted.

Wichita County.

4. In the H. & T. C. R. R. Co. survey 110, about six miles south and a mile and a half west of Electra, a calcareous seam was seen to dip south about ten feet in a mile.

5. On a creek near the west line of Wichita County and about three and a half miles north of the Fort Worth and Denver Railroad a sandstone dips about fifteen feet to the west in the distance of one-fourth of a mile.

6. In the breaks about the waterworks tank a half mile west of Electra the formations show no appreciable dip in a distance of one-fourth of a mile.

7. A dark limestone which is known to be at a depth of about 105 feet below the level of the railroad station at Electra, was penetrated by a well near the northwest corner of the H. & T. C. R. R. Co. survey 27, four and one-half miles south and two miles west of Electra, at a depth of two hundred and ten feet below the level of the Electra Station. This shows a dip between the two places of 105 feet to the southwest, or about twenty feet to the mile.

8. At a point about one and one-fourth miles southwest of Electra a small dip to the west was noted.

9. A calcareous sandstone overlying a blue shale near the waterworks tank two-thirds of a mile west of Electra is believed to be identical with a similar rock seen in the breaks a half mile southeast of Electra. The elevation is about the same in the two places.

10. About a mile south of Electra the upper one of the two calcareous members in the exposed section was observed at two points half a mile apart, on an east and west line, about on the same level at tho two places.

11. Along the east side of the H. T. & B. R. R. Co., about one and one-fourth miles south and one-half mile east of Electra a sandstone lies horizontal.

12. A thin calcareous layer seen on the bank of a creek about a mile and a half north-northeast of Electra railroad station, was identified with a similar stratum seen one-half mile southeast of Electra. In both places this layer lies about thirty-five feet below the elevation of the station, showing that the strata are practically horizontal between these two points on a north and south line.

13. A sandstone appearing in the bed and south slope of a creek one-half mile southeast of Electra dips some eight feet to the northwest in about one-tenth of a mile.

14. At a point about three miles north and one mile east of Electra the formations apparently lie horizontal on an east and west line for a distance of one-fourth of a mile.

15. In the H. & T. C. R. R. Co. survey 25, nine miles south and one and one-half miles east of Electra, a thin dark limestone layer has a dip of about fifteen feet to the north in one mile.

16. Along the creek running through the oil fields north of Electra and northeastward a calcareous stratum which follows the creek on the south side has no appreciable dip in a distance of three-fourths of a mile.

17. In the hills north of Wichita River about five miles west-southwest of the mouth of Beaver Creek, the strata show no dip in a distance of one-half of a mile.

18. In the southeast quarter of the J. A. Roesh survey 8, about two and one-half miles south and one and one-half miles east of Electra, the formation lies horizontal.

19. About four and a half miles north and one mile east of Electra, on the east side of China Creek, the formations lie horizontal.

20. Near the center of the south line of the J. A. Roesh survey 12, about two miles southeast of Electra, is a thin calcareous stratum capping some low banks on the south side of a creek. This stratum dips about ten feet to the east in the distance of a mile.

21. The principal two calcareous members in the exposed part of the general section in Wichita County lie about sixty-five feet apart vertically. Two aneroid measurements were made in an hour's time on the difference of elevation of two outcrops of these members, five miles apart, the upper member outcropping at a point about one mile southeast of Electra and the lower member outcropping north of the old Waggoner ranch, about six miles south and three miles east of Electra. The difference in elevation of these two points measured just sixty-five feet, indicating that the strata lie practically horizontal on a line between these points.

22. On the north side of Beaver Creek about one mile east of School Number 5, and about four miles west of the mouth of this creek, a dark limestone was seen to descend about twenty feet to the west in one mile.

23. Near the southeast corner of H. T. & B. R. R. Co.'s survey 3, six miles south of Electra and two miles east, the sediments seem to lie in a horizontal position.

24. The two highest hills in the W. W. Carroll and the H. & G. N. R. R. Co. surveys, respectively about two and a half and four miles east and each about three and one-half miles south of Electra, are both capped by a sandstone which appears to have once been continuous between the two. The distance between the two hills is about a mile and a half, and the rock capping the east hill lies about fifteen feet lower than the rock on the top of the west hill.

25. Near a tank in the northeast corner of the H. T. & B. R. R. Co. survey 1, four miles south and three and one-fourth miles east of Electra, a thin limestone outcrops which is also seen a mile farther south at about the same level.

26. The two highest points of land seen about three and a half miles east and respectively about two and three miles north of Electra, on the D. L. C. R. R. Co. survey and on the Rich. Mead survey, show a sand which caps the southernmost hill and appears on the upper slope of the northernmost of these two hills. There is a

descent of this rock of about forty feet to the northeast in a distance of about three-fourths of a mile.

27. A thin calcareous seam dips to the northeast some fifteen feet in a mile on surveys S. A. & M. G. R. R. Co. 1, and A. J. Shaw 16, about three and one-half miles east of Electra.

28. Near the northwest corner of the Emma Flemins survey no. 8, about three and one-half miles south and five miles west of Burk, a sandstone which also appears in some hills about three-fourths of a mile to the northeast of this place, is seen to descend about fifteen feet in this distance and direction.

29. In the bluff point between Beaver Creek and Wichita River, on the L. C. Gibbs survey, a mile southwest of School Number 16, the sediments lie horizontal.

30. At a point about four and one-half miles east and one and a half miles north of Electra, on the G. C. & S. F. R. R. Co. survey 9, a thin calcareous stratum runs horizontal on a line extending north and south for a distance of a half mile.

31. On the east end of the G. C. & S. F. R. R. Co. survey, about four miles east and one mile north of Electra, a calcareous stratum shows a dip of about four feet to the northeast in one-tenth of a mile.

32. Near the northeast corner of the B. S. & F. survey, seven and one half miles south and four and one-fourth miles east from Electra, the sediments were apparently horizontal.

33. In the upland bluffs extending from east to west in the A. R. Collins survey 20, four and a half miles west-northwest of Burk, a sandstone was seen to lie horizontal for a distance of half a mile.

34. A thin limestone appearing in the northeast part of the C. C. Lamphear survey 2, about six miles southeast of Electra, and also in a creek about one and two-thirds miles northeast from this survey, in the south part of the S. B. Burnet survey 12, three and one-half miles west of Burk, descends some forty feet in this distance to the northeast.

35. In the southwest quarter of A. R. Collins survey 20, about four and one half miles west-northwest of Burk, a sandstone lies at a slightly lower level than a sandstone, apparently continuous with this, seen a mile further north.

36. A sandstone capping a hill in the northeast part of S. B. Burnet survey 12, about three and one-fourth miles to the west of Burk, shows no dip in a distance of one-twentieth of a mile.

37. A low spur of a bank on the south side of Buffalo Head Creek, about one mile to the west-southwest of Burk Station lies at about the same level as a limestone seen in a creek two miles farther west. The rock in the two places is believed to be the same.

38. In a creek on the S. A. & M. G. R. R. Co. survey, and on the survey north of this, eight miles north and three miles west of

Burk, a sandstone lies horizontal for about a fifth of a mile, running in a northeast and southwest direction.

39. Near the west half of the north line of the W. C. Eustis survey 4, four miles north of Burk, a sandstone dips about ten feet to the east in about one-fourth of a mile.

40. On the highest point of the divide between Buffalo Head Creek and Wichita River, three miles south of Burk, the capping rock dips about eight feet to the northeast in about one-sixth of a mile.

41. In the C. T. R. R. Co. survey, about six miles west and two miles south of Iowa Park, the strata run horizontal for a mile on a north and south line.

42. A dark limestone shell which appears on the low slopes north of the Ft. Worth & Denver Railroad near Burk Station lies horizontal for a distance of one-fourth of a mile on an east and west line.

43. A thin dark calcareous shell caps a low escarpment facing north about three-fourths of a mile south of Burk Station. It has a dip of about fifteen feet to the north in one-half mile.

44. In the H. & G. N. R. R. Co. survey 1, two miles north of Burk, a sandstone lies at the same level at two points three-fourths of a mile apart on a line from northwest to southeast.

45. At Finder's Butte, near the south line of Wichita County, about three miles west and one and one-half miles north of Holliday, the strata lie horizontal for the limited distance they are exposed.

46. A little north of the center of the James A. Bradford survey, about a mile and three-fourths southeast of Burk, the strata lie horizontal.

47. On Tenth Cavalry Creek, from one to two miles south of Red River and from eight to nine miles north of Burk, a sandstone runs horizontal for a distance of a half mile on a north and south line.

48. On Tenth Cavalry Creek, about three miles south of Red River and seven and one-half miles north of Burk, a sandstone lies horizontal in the slopes of the creeks for a distance of three-fourths of a mile, extending in a general direction from northwest to southeast.

49. In the west part of the T. E. Williams survey, about six and one-half miles north and three miles west of Iowa Park, a sandstone lies apparently horizontal for some two hundred feet.

50. Along a ravine running north on or near survey 825 abutting on Red River, some eight miles west of Burkburnett and from one and one-half to two miles south of Red River, a sandstone dips about twenty feet in a half mile to the north.

51. About one mile west of School Number 9, on the west part of the T. T. R. R. Co. survey A 376. some nine and a half miles north and two and a half miles west of Iowa Park, there is a dip to the north of some four feet in one hundred. This dip was observed for

a distance of only about one hundred feet in each of two places, about one-fifth of a mile apart.

52. Near the Archer County line in block 18 on the Denton County School Land, league number 41, due south from Iowa Park, a sandstone capping a low hill dips about fifteen feet in one-fourth of a mile to the northwest.

53. Near the north line of blocks 5 and 6 of the Palo Pinto County School Lands, about six miles south of Iowa Park, a sandstone caps a ridge running about a mile from east to west. There is no discernible dip in this distance.

54. In the B. B. R. R. Co. survey north of School Number 13, about five miles north of Iowa Park, a sandstone was noted which appeared again north of Gilbert Creek. This sandstone had a variable dip to the south, estimated at fifty feet to one mile for a short distance.

55. In the north part of block 12 of the Palo Pinto County School Lands, four and a half miles south of Iowa Park, a sandstone appears on a slope following the east side of a ravine running north. This sandstone dips north about thirty feet in a half mile.

56. A sandstone appearing in the south part of Iowa Park and underlying the north part of the town lies in a horizontal position. Outcrops of a similar sandstone appear on the creeks to the northeast at about the same level. They are believed to be the same sandstone.

57. A half mile north of School Number 18, four miles south of Iowa Park, near the north line of block 19 in the Palo Pinto County School Lands, an outlier of a sandstone caps a hill about eighty feet high. This sandstone dips about fifteen feet to the northeast in one-fifth of a mile.

58. About one-fourth of a mile north of School Number 18 in block number 19 of the Palo Pinto County School Lands, four miles south of Iowa Park, a sandstone dips about fifty feet in one-fifth of a mile to the north.

59. Near the south line of block 12 in the Denton County School Lands, league number 4, a sandstone which caps a low escarpment facing to the south lies fifteen feet lower than a sandstone which caps a low hill a half mile to the southwest. The two sandstones are evidently the same stratum.

60. Near the east line of blocks 20 and 35 of the Palo Pinto County School Lands, three and one-half miles south and one mile east of Iowa Park, an escarpment facing west is capped by a sandstone which dips north thirty feet in a half mile.

61. About three and a half miles west and one-half mile south of Burkburnett, a sandstone following the east bank of a creek running north shows a dip to the north of about four feet in three hundred.

62. Near the north end of W. W. Carroll survey 4, about three and one-half miles south and one-half mile west of Burkburnett, a sandstone dips twenty feet in one-third mile to the north.

63. In the south half of survey 4, four and one-half miles south and one mile west of Burkburnett, a small sandstone dips south about five feet in a fifth of a mile.

64. In the hills and ravines draining north in the W. W. Carroll and J. Johnson surveys, about three and one-half miles south and one-half mile west of Burkburnett, a somewhat discontinuous sandstone, or sandy horizon, shows a dip to the north of about twenty feet in one-half mile.

65. The sandstone capping some hills at a point in the northeast part of the C. T. R. R. Co. survey, three miles south of Burkburnett, is apparently continuous with some sandstone seen on Gilbert Creek two miles to the west. The elevation is about the same in the two places.

66. A sandstone capping some small hills southwest from the railroad bridge across Gilbert Creek, about three miles south and one-half mile east of Burkburnett, has a dip to the east of about eight feet to one-twentieth of a mile. It could be made out for a distance of only three hundred feet, and may represent the original conditions of deposition.

67. A half mile to the southwest of the E. F. Austin survey, about three miles southwest of the Union Station in Wichita Falls, the strata exposed lie in a horizontal position.

68. A sandstone which caps the south bank of Wichita River from the city cemetery to half a mile farther southwest is apparently continuous with the sandstone underlying the south half of the city of Wichita Falls. It shows no determinable constant dip but is practically horizontal for two miles, roughly, east and west.

69. At the east end of Lake Wichita, along the west side of the Wichita Falls and Southern Railroad, a sandstone followed for a distance of a fifth of a mile lay horizontal, on a line from northwest to southeast.

70. A sandstone in the north bluffs of Wichita River north of Wichita Falls lies horizontal in the bluffs for a distance of two miles east and west. The same sandstone appears again at the same level in the south slope to a creek three miles north of the Wichita River bluff.

71. South of the irrigation canal, about one and one-half miles south and a little east of the pumping station of the Wichita Falls Waterworks, a sandstone capping of the edge of the upland lies practically at the same level for the distance of three-fourths of a mile north and south.

72. In the railroad cuts near the pumping station at the tank between the Ft. Worth & Denver and the Missouri, Kansas & Texas

Railroads, about a mile east of Wichita Falls, a sandstone lying horizontal is exposed for about one-tenth of a mile.

73. A low escarpment following the east side of Holliday Creek, about one mile southeast from the Wichita Falls Waterworks pumping station, is capped by a sandstone which dips about fifteen feet in one-half mile to the northwest.

74. Following, roughly, the east line of Wichita County, beginning about a half mile north of the Wichita Valley Railroad and continuing for about a mile to the north, is an escarpment facing to the west capped by a sandstone showing no dip either north or south.

Clay County.

75. On the east bluffs of the Red River, about one and one-half miles down stream from the Clay-Wichita line on the R. E. Sawdon survey, a sandstone lies practically horizontal for a mile in a line northeast-southwest.

76. In the east bluffs of the Red River, about five miles down stream from the Clay-Wichita line, on the F. M. Tucker survey, a well defined sandstone shows a slight dip for half a mile a little south of east.

77. On the M. Bryan survey, about one mile northeast of the preceding observation, a sandstone capping a hill north of a small creek shows a dip to northeast of eight feet in three-fourths of a mile. No corresponding point could be seen south of the creek.

78. In the breaks east of the Wichita River, in the west part of the H. T. & B. R. R. Co. survey 36, about seven and one-half miles west and one and one-half miles south of Petrolia, three ridges extending from west-northwest to east-southeast show sandstones dipping not less than one hundred and twenty feet in one-fourth of a mile to the south-west.

79. About a mile and one-half northeast of observation No. 78, beginning on the H. S. & S. E. Wolf survey and extending into the R. T. Mitchell survey, a sandstone shows horizontal position from all directions. It is continuous for a mile or more.

80. In the hills one mile south of the Wichita River and five and one-half miles west of Petrolia, the strata appear to be horizontal.

81. In the breaks south of the Wichita River, on the E. Story survey 48, about five miles west of Petrolia, a sandstone dips fifteen feet to south, on a north to south line, in one-half mile.

82. Near the southwest corner of the K. McKenzie survey, five miles west and two and one-half miles south of Petrolia, a sandstone in a slope facing north shows a small dip to the south. No sandstone was noted at the corresponding height in the slopes a half mile farther north.

83. In the breaks on the east side of Wichita River on the H. T. & B. R. R. Co. survey, five miles west and one mile north of Petrolia, the rocks lie horizontal.

84. On and north of the W. Richardson survey, four and one-half miles west of Petrolia, there appears to be a slight dip to the southwest.

85. Near the north line of the S. P. R. R. Co. survey 52, four and one-half miles west and one-half mile south of Petrolia, the rocks lie horizontal.

86. In a place about four and one-half miles south and a half mile east of Halsell, in the north half of the H. & T. B. R. R. Co. survey 5, is a dip to the southwest of about eight feet in one-tenth of a mile, showing in the capping sandrock on a hill.

87. In the bluffs on the east side of the Wichita River, west-northwest of Petrolia in the Mrs. E. A. Glasgow survey, the sandstones have apparently no dip.

88. Near the center of the north line of the H. T. & B. R. R. Co. survey 1, about three and one-half miles south and one mile east of Halsell, a sandstone shows a dip to the south of some twenty feet in one mile.

89. In the bluffs east of the Wichita River south of the bridge four miles northwest of Petrolia a sandstone lies horizontal.

90. In the hills about four miles east and four miles south of Halsell the rock lies horizontal.

91. Near the boundary between surveys 12 and 31 of Byers Brothers' subdivision, one mile west of Petrolia, a sandstone has a low dip to north extending one-half mile.

92. In survey 62 of the Byers Brothers' addition, about one and one-half miles northwest of Petrolia, a sandstone which caps an escarpment facing to the west, dips fifteen feet to the northeast in one-fourth mile.

93. About a half mile northwest of Petrolia a sandstone in a creek lies horizontal.

94. Near the center of survey 13, of Parker County School Lands, one and a half miles south-southeast of Petrolia, there is a dip of ten feet in one-half mile to the southwest.

95. Near the south line of survey 13, in the Parker County School Lands, a mile and one-half south and a mile east of Petrolia, a sandstone apparently dips ten feet in one-fifth of a mile, on a north and south line, to the south.

96. In a north slope on the south side of a draw two and one-half miles south-southeast of Petrolia, a sandstone exposure trends east and west and in the distance of one-half mile the rock dips some ten feet to the west.

97. In the southeast part of survey 100 in the Byers Brothers' subdivision, about one and one-fourth miles southwest of Byers, is a dip of some ten feet to the north, on a line running north-northwest, in one-half mile.

98. The lower sandstone appearing in a hill one and one-half miles northeast of Petrolia dips about fifteen feet to the north in one-fourth of a mile.

99. In the bluffs one mile northwest of Byers the rocks lie horizontal for two miles in a northeast-southwest direction.

100. In the north half of survey 3 of the Parker County School Lands, a mile and a half southeast of Petrolia, a sandstone dips some twenty feet to the northeast in one-half mile.

101. Near the center of survey 72 of the Parker County School Lands, three and three-fourths miles south and two and a half miles east of Petrolia, there is a doubtful small dip to the south.

102. A mile and one-fourth east-southeast of Petrolia, near the south line of survey 16 of the Byers Brothers' subdivision, a sandstone dips fifteen feet in one-fourth mile to the east.

103. Three and a half miles south and two and a half miles east of Petrolia, near the center of the south line of survey 61 of the Parker County School Lands, a sandstone lies horizontal on a north and south line a distance of one-half mile.

104. In the west half of block 4 in the Parker County School Lands, not quite two miles southeast of Petrolia, a sandstone cropping out on a slope to the northwest dips some ten feet to the northeast in one-fifth of a mile.

105. One mile south of Byers there appears to be a dip to the north of some ten feet in one-fourth mile.

106. Near the northeast corner of survey 25 in Byers Brothers subdivision, two miles east and one-half mile north of Petrolia, a thin sandstone lies horizontal.

107. At a point about two and one-half miles east and one mile south of Petrolia, near the north line of survey 6 in the Parker County School Lands, the rock lies horizontal, as near as could be made out.

108. In survey 96 of the Parker County School Lands, three and one-half miles east and four and one-half miles south of Petrolia, there is apparently a small dip to the south.

109. In surveys 9 and 20 of the Parker County School Lands, about four miles east and one mile south of Petrolia, a sandstone caps a ridge extending in a north and south direction. This sandstone dips twenty feet to the north in a distance of one-half mile.

110. In the Mrs. Holland survey 21, four and one-half miles east and one mile north of Petrolia, a sandstone capping a low escarpment facing north dips about fifteen feet in a half mile to the east.

111. At a point about seven miles south and five miles east of Petrolia the rock lies horizontal.

112. In the hills one-half mile southeast of the northwest corner of the Montague County School Lands, five and one-fourth miles east and one mile north of Petrolia, a sandstone dips twenty feet in one-third mile to the north.

113. In the hills one-half mile east of the northwest corner of the Montague County School Lands, five and one-half miles east and one and one-half miles north of Petrolia, a sandstone dips twenty-five feet to the north in one-half mile.

114. In the hills about Dickworsham a sandstone lies apparently horizontal for a distance of a half mile from the station.

115. At a point about eight and one-half miles east and six miles south of Petrolia the rocks lie horizontal.

116. In the northwest quarter of section 8 of the Montague County School Lands, nine miles east and one and one-half miles south of Petrolia, the rock lies horizontal for a distance of about one-half mile.

Below is a classified list of the observations given above of places showing dips or horizontal positions of the Wichita formation.

Classified Table of Dips.

NORTH DIPS.

Series number.	Observed distance in miles (horizontal length of dip).	Observed amount of dip in feet.
15	1.00	15
43	.50	15
50	.50	20
51	.04	8
55	.50	30
58	.20	50
60	.50	30
61	.06	4
62	.33	20
64	.50	20
91	.50	10
97	.50	10
98	.25	15
105	.25	10
109	.50	20
112	.33+	20
113	.50	25

NORTHEAST DIPS.

Series number.	Observed distance in miles.	Observed amount of dip in feet.
26	.75	40
27	1.00	15
28	.75	15
31	.10	4
34	1.66	40
40	.16	8
57	.20	15
50	.50	15
77	.75	8
92	.25	15
100	.50	20
104	.20	10

EAST DIPS.

Series number.	Observed distance in miles.	Observed amount of dip in feet.
20	1.00	10
24	1.50	15
39	.25	10
66	.05	8
76	.50	10
102	.25	15
110	.50	15

SOUTHEAST DIPS.

(None noted.)

SOUTH DIPS.

Series number.	Observed distance in miles.	Observed amount of dip in feet.
35	1.00	10
54	.20	10
63	.20	5
81	.50	15
82	.50	5
88	1.00	20
96	.20	10
1	4.50	50
2	1.00	15
4	1.00	10
101	.50	5
108	.50	5

SOUTHWEST DIPS.

Series number.	Observed distance in miles.	Observed amount of dip in feet.
78	.25	120
84	.50	5
86	.10	8
94	.50	10
8	.50	10
7	5.00	105

WEST DIPS.

Series number.	Observed distance in miles.	Observed amount of dip in feet.
22	1.00	20
96	.50	10
5	.25	15
8	1.00	10

NORTHWEST DIPS.

Series number.	Observed distance in miles.	Observed amount of dip in feet.
13	.10	8
52	.25	15
73	.50	15

Horizontal Positions (No Dip).

NORTH AND SOUTH.

Series number.	Observed distance in miles.
71	.75
74	1.00
103	.50
12	2.00
30	.50
41	1.00
47	.50

EAST AND WEST.

Series number.	Observed distance in miles.
65	2.00
68	2.00
70	2.00
9	1.50
10	.50
14	.25
37	2.00
42	.25
53	1.00

NORTHWEST AND SOUTHEAST.

Series number.	Observed distance in miles.
69	.20
21	7.00
44	.75
48	.75

NORTHEAST AND SOUTHWEST.

Series number.	Observed distance in miles.
75	1.00
90	2.00
16	.75
38	.50
56	.50

ALL DIRECTIONS.

Series number.	Observed distance in miles.
18, 19, 23, 25, 32, 33, 36, 46, 80, 83, 85, 87, 89, 90, 93, 106, 107, 111, 114, 115—each .25 mile	5.25
17, 67, 79, 116—each .5 mile	2.00
45, 72—each .1 mile	.20
36, 49—each .05 mile	.10
11	.20

Absence of Dips.

It will be noted that fifty-six observations show the beds lying horizontal. In twenty-nine of these places the rock appeared to lie horizontal in all directions of the compass for a distance, arbitrarily fixed in the table, at a fourth of a mile from the point of observation. The remaining twenty-five horizontal positions noted were observed for definite directions and measured distances. The alignment of these defined directions to the cardinal points of the compass indicates that the rocks in this area most frequently lie horizontal in the directions which are nearest to a line running from west-northwest to east-southeast. This is even more decidedly indicated by the sums of the combined distances of measured horizontal positions, as will appear from the figures in the following table.

TABLE SHOWING FREQUENCIES AND DISTANCES OF DIFFERENT DIRECTIONS OF OBSERVED HORIZONTAL POSITIONS OF ROCKS IN WICHITA COUNTY, IN THE EAST BORDER OF WILBARGER COUNTY, AND IN THE NORTH HALF OF CLAY COUNTY.

Directions of observed horizontal positions of rock strata.	Total distances measured in miles.	Number of places noted.
North-south	6.25	7
Northeast-southwest	4.75	5

East-west	11.50	9
Northwest-southeast	8.70	4
Arbitrarily, in all directions	7.40	29

General Features of the Dips.

In making observations on dips, the horizontal distances were for the most part estimated, sometimes with the aid of known positions of gates and fences. In a less number of cases, and always in the case of the highest dips, the distances were obtained by pacing, or by a car cyclometer. In every case the distances were expressed in some simple fraction of a mile. The fractions used and the number of times each was used are as below:

	Number of times observed.
One twenty-fifth mile	1
One twentieth mile	2
One tenth mile	3
One sixth mile	1
One fifth mile	6
One fourth mile	8
One third mile	2
One half mile	21
Three fourths mile	3
One mile	9
One and one-half miles	1
One and two-thirds miles	1
Four and one-half miles	1
Five miles	1

Reducing all observations on dips to rates of dip in feet per mile, irrespective of the distance for which they were made, these rates may be conveniently referred to five groups, for a rough presentation of the class of structures they represent, as below:

	Groups of dip.	Number of observations.	Average dip of each group in feet per mile.
1.	Dips of 24 ft. per mile or less	20	15
2.	Dips of 25 to 49 ft. per mile	16	36
3.	Dips of 50 to 74 ft. per mile	15	57
4.	Dips of 75 to 99 ft. per mile	5	79
5.	Dips of 100 ft. per mile, or more	4	272
6.	Maximum rate of dip noted		480

It will be seen that the fifth group differs very considerably from the other groups in its rate of dip. None of these high dips were found to have any great horizontal extent. It is believed that they are limited in extent, and they may be partly due to original tilting in bedding, though this is not believed to be the main cause of the tilts in these particular instances.

Prevailing Directions of the Dips.

If we inquire into the distribution of these dips among the different directions of the compass, we find that they give strong evidence of the existence of a definite trend in some existing gentle deformations. They are, however, almost the only visible superficial evidence which we find of such deformations. It will be remembered that rocks were most frequently found lying horizontal in a west-northwest to east-southeast direction. Correspondingly and inversely, we have found the greatest number of dips to extend in a north-northeast to south-southwest direction, as might have been expected. And in the case of the dips the evidence of such an unequal and significant distribution is quite conclusive. It is evident from the number of observations made on dips in different directions, from the total horizontal distances along which dips have been observed in each direction, and from the amount of descent of strata in each direction. This will be apparent from the following table:

Direction of dip.	Number of dips noted.	Total horizontal distance of dips, in miles.	Total amount of dips (descent of strata), in feet.
East	7	4.05	83
Southeast	0	.00	0
West	4	2.75	55
Northwest	3	.85	38
North	17	6.95	322
Northeast	12	6.82	205
South	12	11.10	160
Southwest	6	6.85	258
The four directions nearest to a W.N.W.-E.S.E. axis	14	7.55	176
The four directions nearest to a vertical to a W.N.W.-E.S.E. axis	46	31.62	945

The difference in the alignments of the distances of observed horizontal and dipping rocks to points of the compass is most clearly apparent, if the proportionate distances of each dip and horizontal attitude noted be laid off on lines extending in the observed directions. In figure 6, representing the horizontals, the longest lines extend in a west-northwest—east-southeast direction, while in figure 7, representing the dips, the longest lines extend north-northeast—south-southwest. More exact treatment of these data places the trend required by the horizontal observations at about 28 degrees south of east and north of west, and the trend required by the observations on the dips at about 29 degrees north of west and south of east.

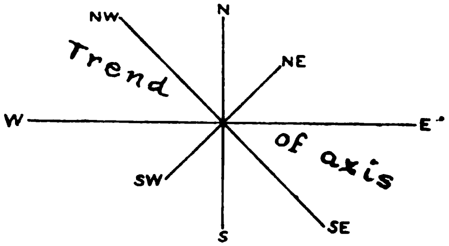


FIG. 6. Lines proportionate in length to the distances for which 54 observations show the rocks to lie horizontal in the directions indicated by the radiating lines. The probable trend of indicated folds is also shown.

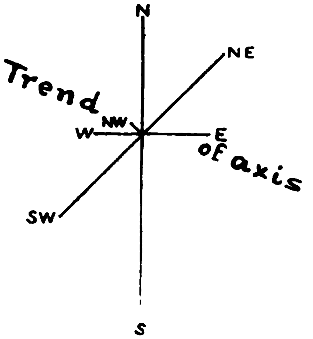


FIG. 7. Lines proportionate in length to total distances for which 60 observations show dips in several directions, as indicated by the radiating lines. The probable trend of indicated folds is also shown.

Indicated Trend of Existing Folds.

There is good reason to believe that all these data may properly be regarded as chance observations on one or more very shallow and wide folds, anticlines and synclines, trending in an east-southeast to west-northwest direction. In fact, we find that at least one system of dips shows an anticline with such a trend near Petrolia. See Plate I.

East and West Structure.

Our main object in making these observations was to procure some evidence bearing on the gross structure of this region; to learn, if possible, the general attitude of the rocks in the whole area studied, and in particular to obtain data for correlating the general section penetrated by the wells at Petrolia with the general section explored in the wells at Electra.

If we regard all the observations made in the area between Electra and Petrolia as chance observations on the general attitude of the formations, we can estimate from them the probable dip of the terrane on an east and west line. Leaving out all observations west of Electra and all east of the Henrietta (Petrolia) field, thus taking only the numbers from 10 to 100, inclusive, in the list of dips given, and leaving out also dips noted on a north or south line, since these would have no effect on the general east to west attitude of the terranes, we find that a total dip of 30 feet to the west was noted in two places for a combined distance of one and a half miles. Similarly we find a total dip to the east of 53 feet in four places, for a combined distance of 3.33 miles. This represents a dip of 23 feet to the east in a distance of 4.83 miles. The formations were also seen to lie horizontal on an east to west line in 31 places for a combined distance of 17.33 miles. On lines running from east to west the dips noted in 37 localities therefore show on the whole a descent to the east of 23 feet in 22.16 miles. If we similarly figure the dips noted on lines directed northeast, southwest and northwest, and project these distances, and also the slant of the planes in which these dips lie, on an east and west vertical plane, we find the remaining observations show a dip of 5 feet to the east for a combined distance of 23.60 miles.

To sum up: 90 observations, combined, show a general dip to the east of 28 feet between Electra and Petrolia. If these ninety observations between Petrolia and Electra signify anything, they indicate that the formations lie essentially horizontal, on an east and west line in this area. A stratum known to lie at a certain depth under the surface near Petrolia should be found as much deeper under the surface at Electra, as the elevation there is higher. The difference in elevation of the two fields is about 250 feet. Hence a stratum lying 750 feet below the surface at Petrolia should be looked for 1000 feet below the surface at Electra, and a horizon lying 1600 feet below the surface at Petrolia should lie 1850 feet below the surface at Electra, unless there be a change in the thickness of the formations.

THE UNDERGROUND FORMATIONS.

Data secured on the formations penetrated by deep borings remain our chief recourse for information on the deeper stratigraphy of the area. In some respects these data are even more unsatisfactory than the data secured by examination of the surface. The operators have very generously placed a large amount of material at our disposal for study. A number of well records from the two fields explored have been obtained. We have obtained in all some more or less complete records of 226 wells. Many of these records will be found in the Appendix.

A closer inspection of these records shows that some of them are somewhat unreliable. In the Electra field we find two wells, Numbers 65 and 66, only some 250 feet apart. A stratum which in one of these wells is called "sandstone," is in the other called "hard shell rock." In the Henrietta field "gyp rock" is several times reported in some wells from depths where limestone is reported in other wells. Nor are such inaccuracies at all surprising. The development of the Electra field has been rapid, and in the rush and hurry attendant on the opening of a new field there is but little attention given to the making of accurate determinations of the rocks explored. The drillers are usually required to keep a log of the formations penetrated, but their chief concern is to make the hole without accident in as short time as possible, and to detect the presence of oil or gas in the sands. It is only in exceptional cases that the driller is expected to give close attention to the nature of the ground, as in the making of some wildcat wells, where the object is to study the field as much as to bore for oil or gas. In the case of many other wildcat wells hardly any attention is given to keeping a record, the sole purpose being to test some expected fuel bearing stratum.

Many of the drillers in these fields have had their previous training in the oil fields of the coast and at Corsicana, and they have brought with them to this field the descriptive terms in vogue in the fields where they had their training. The formations in this field are quite different from the formations of the coast. They are much older than the formations either of the coast or of the Corsicana field. Most of the clays here are of slightly firmer consistency than in the other fields. The terms "gumbo" and "mud," which have been so freely used here, are less applicable in North Texas than in the coast country. In a number of instances the drillers in this new and unfamiliar field have made use of some noncommittal terms, such as "rock," "hard rock," and "red rock," and "red formation." Such terms require interpretation.

Drillers' Descriptions.

For the purpose of familiarizing ourselves, as it were, with the drillers' nomenclature, we have made a quite extensive study of the names and descriptive terms and phrases used by the drillers. For this purpose we have selected the logs of thirty-seven wells near Petrolia and of ten wells in the Electra field. We have classified the terms used in these records according to our own interpretation of their exact meaning and have noted the number of times each of the terms have been used and the thickness of the several strata they describe in each case. Incidentally this treatment of the data gives us valuable information on the general nature of the terranes explored, and an attempt has been made to use this information also for roughly verifying our correlations of the formations in the two principal fields where these explorations have been made. All the wells studied have a combined depth of 81,153 feet. Below is a table showing the number of times different rocks, expressly named or inferred to be present by interpretation, have been reported, the average thickness and the total thickness of each, as well as the percentage each makes of the total thickness of rocks studied.

Kinds of rock.	Number of times noted.	Average thickness in feet.	Total number of feet reported.	Percentage of all observations.
Gravels	6	7	45	.05
Sandstones	350	42	14,866	18.30
Argillites (shale, clay, mud, etc.)	579	92	58,290	65.60
Limestone	33	27	881	1.10
Gypsum	17	28	478	.50
Surface deposits	11	16	181	.20
Mixtures	94	79	7,445	9.30
Gypsum and other minerals	25	13	335	.40
Unidentified rocks	75	48	3,632	4.50
All rocks	1,196	39.4	81,153	99.95

GRAVELS.

To gravels we have referred four instances of rock reported by drillers as "granite." None of the rock reported as granite was more than a few feet thick and in each case the stratum rested on the usual sediments, clays or sandstones. We found in the belt of country outside of the east boundary of the Wichita formation several thin gravels, which consisted largely of granite pebbles.

In one sense this determination of the drillers is correct, for no doubt the cuttings contained fragments of real granite, when the drill was crushing such gravels. But it is certain that no granite has been encountered *in situ* in any of the wells. Only one sample of gravel from any of the wells was examined. This was from the Bacon well at 1400 feet. It contained some pebbles from 4 mm. to 1 mm. in diameter, most of which were chert, while some were orthoclase, evidently from granite. It does not seem that any of the mud lump conglomerates noted in the outcrops of the Wichita formation have been noticed by the drillers as gravels. This is no doubt due to the softness of the constituent pebbles in those conglomerates. Nothing softer than quartz or feldspar would withstand the impact of the drill sufficiently to have the appearance of gravel in the drillings. Gravel was identified as such in the well records only in two cases, and the combined thickness of these two gravel beds was twenty-seven feet. It will be remembered that the granite gravels were much thinner, averaging less than five feet. One would expect the coarser granite gravels to have a smaller development than finer chert gravels, and such appears to be the case.

SANDSTONES.

We find that undoubted sandstones has been reported under several different designations. The softer beds, which are the more frequent, are generally reported as "sand." When more indurated, they have been called "sand rock," or "rock sand." "Rock and sand" is perhaps to be classified as sandstone, though this seems somewhat uncertain, especially as 230 feet of this was noted as one bed. "Sand shell" is a term used for a thin sandstone, especially if it be somewhat indurated, and perhaps cemented by a calcareous matrix. "Sand boulders" are reported in four instances. Drillers report hard rock as "boulders," when they infer from the behavior of the drill that the hard material on which the bit is working shifts its position under the impact of the tool. It is hardly probable that boulders of sandstone have been penetrated in any of these wells. But we have seen that large concretions occur in some sandstones in Clay County, and it is not impossible that concretions may, sometimes, be so much more indurated than the sandstone in which they are imbedded, that they might be jarred loose by the drill from the rest of the rock, especially if this should be soft and thin. In such case a large sandstone concretion might react on the drill in the same way as a boulder. Possibly, also, thin strata of indurated sandstone when imbedded in soft rock, might appear to behave like a boulder to the drill. The following table shows the frequency of different terms in reporting sandstones.

Driller's names.	Number of times used.	Total thickness reported in feet.
Sand	248	8,842
Sand rock	105	5,706
Rock and sand	1	230
Rock sand	1	60
Sand boulders	4	19
Sand shell	2	9

SHALES AND CLAYS.

Argillaceous beds constitute about seventy per cent of all the material described in the well records examined. Sixty-five per cent have been identified as some kind of argillite, and in the nine per cent of mixtures reported and four per cent of unidentified material there is no doubt enough additional argillites present to make five per cent more of the total. The larger amount of argillites and their many variations in color, texture and contents has caused them to be reported under different descriptive terms and phrases, as shown in the following list:

Driller's names.	Number of times used.	Total thickness reported in feet.
Shale	227	21,141
Mud	164	16,002
Gumbo	41	2,724
Slate	32	1,622
Clay	27	3,115
Qualifying terms alone, as "red," "blue," etc.	20	2,930
Mud and boulders	13	608
Gumbo and boulders	8	640
Mud and rock	7	442
Formation	5	1,944
Cave	5	591
Shale and mud	5	263
Talc	5	44
Shale and gumbo	4	418
Shale and boulders	4	178
Gumbo and rock	3	120
Shale and rock	2	69
Clay and boulders	1	150
Soapstone	1	70
Shale and clay	1	36
Soapstone and rock	1	30
Slate and mud	1	22
Slate rock	1	19
Shale rock	1	3

"Shale" is the name used most frequently and for the greater part of the argillites. "Mud" is evidently a term which has been introduced by drillers from the gulf coast. In the parlance of the driller, "mud" is, in this field, a soft clay or shale, which more readily than other argillites mixes or dissolves in water and thus forms mud. In texture the muds are perhaps slightly coarser than the clay, and they are not as indurated as shale, the constituent particles of the mud being more readily parted by the capillary influx of water than those in shale or in clay of the finest texture. It is quite probable that this difference in behavior may be, to some extent, due to the salinity of the water used in drilling or held in the argillites, and that these terms do not necessarily imply any real difference in the texture of the insoluble constituents of the rock itself. "Gumbo" is another term which seems to have been introduced by the drillers from other fields. It denotes a clay which produces a thick, sticky mud that "gums" on the bit or that adheres to the bit firmly. Some drillers are of the opinion that gumbo is especially abundant in the most productive wells. The gumming of the clay may, no doubt.

be caused by the presence of secondarily introduced ingredients, as well as by its original texture. "Slate," which is reported in two cases, is known by its coherence, causing a large part of the rock to appear as thin fragments in the drillings. It has been most frequently noted in the deeper parts of the wells. "Clay" seems to be used for designating the soft argillites of finest texture. The difference between mud, gumbo, and clay is necessarily in many cases slight and there can be no doubt that these terms do not always imply exactly identical distinctions. Sometimes the logs give only the color of the rock penetrated, when it is quite apparent that the full phrase should be "red clay" or "blue shale." In a few cases the word "formation" is used, when from the context it appears that this noncommittal term stands for the name of some argillite. "Cave" is a term used as a name for an argillite which caves into the boring. "Talc" and "soapstone" have been used incorrectly a few times for reporting some clay or shale of fine texture and light color. Neither is to be found in these fields. In twenty-six cases "boulders" are reported as present in gumbo, mud, shale or clay. It is not believed that these are real boulders, for no boulders are known in outcrops of these beds. They are most likely concretionary structures of dark and compact clay-ironstone, also known as septaria and sometimes characterized by fissures filled with calcite spar. Under the drill these might react in the same way as boulders.

LIMESTONES.

Only one per cent of the reported rock consists of limestone. The designations used, and the measurements, are as in the following table:

Driller's names.	Number of times used.	Total thickness reported in feet.
Lime	11	90
Lime shell	7	205
Lime rock	6	80

Limestone is reported in notably unequal amounts in some wells which are not far apart, and it is quite certain that some drillers have failed to report some limestones and that others have reported some rock as limestone which really has been calcareous sandstone. While there can be no doubt that errors have crept in, it is unsafe to guess in what direction there are the most errors. It must be left to later observers to make the correct interpretations. Meanwhile, it appears most useful to give the original records as they were made.

GYPSUM BEDS.

Gypsum has been reported from the deeper part of several wells as "gyp rock" in fifteen cases and twice as "gypsum." While we have found no gypsum in any of the well samples some of these reports may be correct. The fact that gypsum has been reported at several depths in a few wells, while none has been noted in most of the other wells, suggests that the gypsum reported may have been some other rock, such as limestone. The same interpretation is suggested by the fact that fifteen feet of gypsum in one well is said to have been "hard." Another two foot stratum of gypsum is described as "shaly."

OTHER ROCKS AND MINERALS.

Some other rocks and minerals have been reported as follows:

Driller's names.	Number of times used.	Total thickness reported in feet.
Flint rock	18	282
Quartz	3	39
Iron pyrite	2	9
Boulders	2	5
Surface	3	103
Surface clay	3	53
Soil	3	14
Quicksand	1	10
Sod	1	1

With regard to what has been called "flint rock" we believe that some of this must have been hard limestone of fine texture. We know of instances where drillers have reported even compact gypsum as flint, when found in the soft shales. Flint has no doubt been encountered in some of these wells, for we have seen some flint in the cuttings of the deeper wells. But it is not likely that flint beds would average as thick as the beds reported here. One of the flint beds reported measured 30 feet, another 45 feet, and still another 55 feet. Nothing like this has been noted in the Pennsylvanian of the Colorado section, in the north part of Texas, and it is not likely to exist here. The interpretation of the reported "quartz" is quite problematic. It may have been a hard sandstone. Iron pyrite we believe to be correct. The surface deposits are in most cases insignificant in these fields and have naturally not often been noted.

MIXTURES.

No less than nine per cent of the thickness of all reported rock is reported as mixtures, or alternations of two, three, or four different kinds of sediments. The alternations of argillaceous and arenaceous sediments are sometimes so rapid that the correct measuring of the strata of each would entail too much attention by the driller and would be to no purpose. This is quite evident from the following list of items, found in the logs examined. In a few cases, the mixed rocks are more than a hundred feet thick, and could no doubt have been reported separately. It is believed that much the greater part of the material in this list consists of argillites.

Driller's names.	Number of times used.	Total thickness reported in feet.
Sand and shale	17	1,141
Mud and gravel	10	1,107
Sand and slate	7	160
Mixture	6	493
Shale and shells	5	304
Sand rock and shale	4	248
Sand and gumbo	3	65
Gumbo and gravel	3	52
Sand rock and red formation	2	995
Gravel and clay	2	333
Sand, shale	2	201
Mud and gypsum	2	180
Duke's Mixture (facetiously)	2	106
Gypsum and gumbo	2	90
Shale and salt	2	45
Mud, cave and sand	1	390
Clay, sand, rock and gumbo	1	266
Shale and flint shell	1	229
Gyp and lime rock	1	180
Rock, gypsum and lime	1	180
Marl and sand shells	1	90
Blue and shells	1	65
Shell and slate	1	60
Shell and gumbo	1	58
Mud and sand boulders	1	50
Shelly rock and gumbo	1	47
Rock and shells	1	38
Rock and shale	1	35
Shale and gravel	1	35
Gypsum and sand	1	33
Shale and streaks of lime	1	29
Soapstone	1	28
Mud and sand shells	1	22
Rock, flint and gyp	1	18
Sand and gravel	1	18
Sand and clay	1	16
Granite and mud	1	15
Gravel and shells	1	12
Marl and shale	1	10
Mixed	1	2

UNIDENTIFIED ROCKS.

Four and a half per cent of the thickness of all reported rocks have not been definitely identified by the drillers. These have been designated as below:

Driller's names.	Number of times used.	Total thickness reported in feet.
Rock	60	3,556
Shell	11	61
Cap rock	4	15

Some of this rock is no doubt sandstone. It seems that one or two drillers have been in the habit of designating all hard material merely as "rock," while using several more descriptive terms for the different argillites. In most of the records the word rock does not occur. "Red rock," which is reported several times, may be some indurated argillite. "Shell" appears to be used for all thin and hard rock strata. It is believed that most such strata in the terrane explored here are thin limestones. "Cap rock" is a term used for any stratum, more or less indurated, which happens to immediately overlie an oil or gas bearing rock.

Frequencies of Different Thicknesses of Beds Measured.

A table was also prepared to show the frequency of different thicknesses of most kinds of rocks described in the well records. This table is as below:

TABLE SHOWING THE NUMBER OF TIMES DIFFERENT THICKNESSES HAVE BEEN NOTED FOR SEVERAL KINDS OF ROCK.

Limits of thickness of beds in feet.	1—9	10—19	20—29	30—39	40—49	50—59	60—69		80—89		100—199	200—299	300—399	400—700
Sandstones	98	60	44	31	20	20	13	7	5	3	18	6	4	2
Argillites (shale, clay, etc.)	58	76	65	12	31	29	30	22	23	18	95	40	16	10
Limestones	23	9	6	1	1	1	2	1	----	----	----	1	----	----
Mixtures	9	19	14	9	4	5	6	3	3	3	4	6	4	1
Undetermined rock	24	10	11	5	2	3	2	1	2	1	4	1	2	2
All other rocks	21	6	6	3	4	1	1	----	----	----	1	----	----	----
All kinds of rock	226	180	146	91	62	50	63	34	33	25	110	79	21	14

Most of the sandstones penetrated are less than 30 feet thick. nearly half of those measuring less than 30 feet are less than 10 feet thick, and only about one-sixth of all the sandstones are 60 feet thick or more. Sandstones measuring more than 9 feet become less and less frequent as their thickness increases.

Thin clay beds are less frequent than thin sands. The most common thickness of argillites is from 10 to 19 feet, but from this maximum there is a much more gradual decrease in frequency for increasing thickness than in the case of the sandstone. No less than 161 beds of argillites measured more than 100 feet. The rate of decrease in frequency with increase in thickness is not continuous, but it appears that argillites measuring from 60 to 69 feet were more often found than such as measure from 40 to 49 or from 50 to 59 feet. If this is not due to some method of inaccurate measuring, as by pole lengths, it may indicate some rhythm in sedimentation, or more likely the actual prevalence of one or two beds of this thickness.

More than half of the limestones measure less than ten feet. The frequencies of different thicknesses in the reported mixtures of rocks are distributed very much as they were in the argillites. This circumstance corroborates our conclusion that the greater part of the reported mixed material is shale or clay.

The last line in the table may serve as a general expression of the closeness of differentiation of the terranes practiced in the making of the records, and also as a general expression of the variations in later palaeozoic formations of this region.

Reported Properties of Rocks.

The phrases used by the well men in describing the formations consist for the most part of only two words, the name of the rock and some qualifying word. In a lesser number of cases there are two qualifying words added to the name. A study of the qualifying terms is quite instructive and aids in making correct interpretations of the records. It remains to briefly summarize some notes on this subject.

Of all the rocks named seventy-eight per cent have been also described by a word designating some property. The number of words used for this purpose is quite small, only a little larger than the number of rock names already noted. The simple rock names are about thirty and the simple qualifying words are about forty. If we count the phrases denoting mixtures of rocks, the list of names is considerably longer than the list of words denoting the properties of rocks. We have seen that 1196 rock strata were given a name. Properties were indicated for 926 of these rock units.

We find that these few terms are used to indicate essentially five groups of related properties, viz.: terms implying properties of color, contents, cohesion, stratification, and texture of the rock named. These groups are shown in the following list:

LIST OF TERMS AND PHRASES DENOTING PROPERTIES, SHOWING THE NUMBER OF TIMES EACH HAS BEEN USED.

Color.		Contents.		Cohesion.		Stratification.	
Blue	200	Oil	63	Hard	88	Mixed	35
Red	175	Water	41	Soft	15	Broken	19
White	81	Gas	33	Loose	4	Shelly	2
Red and blue	46	Salt water	17	Shaly	2	Streaks	2
Black	42	Dry	14	Rocky	2	Stratified	1
Brown	24	Oil and gas	6	Tough	2		
Gray	19	Dead	4	Very hard	2		59
Light	9	Oil and water	8	Cavey	1		
Lead colored	8	Salt water and oil	3	Rotten	1	Texture.	
Blue white	4	Fresh water	2				
Dark grey	1	Dead, little water	1		117	Sandy	5
Blue and brown	1	Salt	1			Fine	2
Red and white	1	Oil and salt water	1			"Putty"	1
Blue and black	1					"Porous fossil"	1
			188				
	612						9

It appears that less than one per cent of the rocks are described as to texture, four and a half per cent are described in some loose way as to stratification, ten per cent are described with regard to cohesion, about fifteen per cent are described as to presence or absence of oil, gas, water and salt, and fifty-two per cent are described with regard to color.

Below is a list showing the number of times each term has been used, the class of sediments to which it has been applied and the total and average thickness of each rock unit described.

ROCKS DESCRIBED AS TO COLOR.

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Argillites—			
Blue	170	17,126	101
Red	143	16,846	118
Red and blue	40	4,874	122
White	37	1,444	39

Rocks Described as to Color—continued.

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Black	28	1,494	53
Brown	17	658	38
Dark	9	705	78
Lead colored	8	720	90
Light	7	554	79
Gray	4	72	18
Blue white	2	238	119
Blue and brown	1	201	201
Red and white	1	25	25
Blue and black	1	20	20
Sandstones—			
White	25	959	38
Gray	13	319	25
Black	8	90	11
Brown	5	65	13
Blue	3	79	26
Red	3	76	25
Dark	2	19	9
Red and blue	1	790	790
Light	1	5	5
Dark gray	1	5	5
Limestones—			
Blue	5	38	7
White	2	24	12
White blue	2	24	12
Gray	1	8	8
Gravels—			
Blue	4	18	4
Red and blue	1	22	22
Surface Deposits—			
Red	1	20	20
Mixtures—			
Blue	17	675	40
Red	13	2,062	159
White	5	138	30
Black	4	110	27
Red and blue	4	76	19
Dark	1	181	181
Light	1	20	20
Brown	1	11	11
Unknown Rocks—			
Red	15	1,608	107
White	12	689	57
Black	2	43	21
Gray	1	20	20
Brown	1	10	10
Light colored	1	8	8
Blue	1	3	3

ROCKS DESCRIBED AS TO STRATIFICATION.

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Argillites—			
Mixed	33	3,941	119
Stratified	1	20	20
Sandstones—			
Broken	13	302	23
Mixed	1	35	35

Rocks Described as to Stratification—continued

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Mixtures—			
Broken	5	63	13
Streaks	2	40	20
Mixed	1	21	21
Unknown Rocks—			
Shelly	2	27	14
Broken	1	36	36

ROCKS DESCRIBED AS TO COHESION.

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Argillites—			
Hard	22	1,323	64
Rocky	2	121	60
Tough	2	68	34
Shaly	1	190	190
Rotten	1	20	20
Cavey	1	19	19
Putty	1	10	10
Sandstones—			
Hard	39	1,040	27
Soft	10	206	20
Loose	3	84	28
Gravels—			
Loose	1	5	5
Hard	1	4	4
Limestones—			
Hard	1	1	1
Gypsum—			
Hard	1	18	18
Mixtures—			
Hard	1	32	32
Soft, rotten	3	57	19
Unknown Rocks—			
Hard	23	370	16
Very hard	2	13	6
Soft	2	31	15
Porous fossil	1	6	6

ROCKS DESCRIBED AS TO CONTENTS.

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Sandstones—			
Oil	54	921	17
Water	41	2,250	55
Gas	32	526	16
Salt water	17	1,425	84
Dry	14	252	18
Oil and gas	5	51	10
Dead	4	29	7
Oil and water	3	83	28

Rocks Described as to Contents—continued

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Salt water and oil	2	157	78
Fresh water	2	48	24
Dead, little water	1	15	15
Argillites—			
Oil	3	68	23
Limestones—			
Oil	1	2	2
Mixtures—			
Oil	2	48	24
Oil and salt water	1	24	24
Unknown Rocks—			
Oil	3	10	3
Gas	2	22	11
Oil and gas	1	4	4

ROCKS DESCRIBED AS TO TEXTURE.

	Number of times noted.	Total thickness described, in feet.	Average thickness, in feet.
Argillites—			
Sandy	5	78	15
Fine	1	6	6
Sandstones—			
Fine	1	17	17
Gypsum—			
Shaly	1	2	2

SIGNIFICANCE OF SOME OBSERVATIONS.

Colors are most frequently noted in case of argillites, nearly 80 per cent of all such sediments having been described as to color. The red color is characteristic of the shales in the upper 1000 feet of the deep wells, the blue and light colored shales are most common in the lower 800 feet. Brown color occurs mostly from 500 to 1200 feet below the surface. The black, brown, and dark sandstones average less than half as thick as the white, gray, blue, and red sandstones. This is probably due to the fact that the coloring material, which is mainly some oxide of iron or manganese, has been secondarily introduced by the ground water, which has had comparatively free circulation in the thicker strata. In the thinner sands the ground water may be supposed to have been more stagnant, giving more time for the precipitating agents to act, or for the impregnating minerals to accumulate. The black color in sandstones is mostly due to the presence of iron pyrite. In the shales it is mostly due to the presence of carbonaceous material in the original sediments. From the colors reported for the mixtures and for unknown rocks the inference may be made that the red mixtures and the undetermined red rocks are mostly argillites, as the average thickness reported of these rocks corresponds most closely to the average thickness of red argillites.

. The terms denoting contents in rocks have been applied to few other rocks than sandstones and to some undetermined rocks, which probably were sandstones, sandy shale or limestone. Forty-nine per cent of all sandstones have been characterized in this respect. The presence or absence of water has apparently not always been noted. Dry sand was noted in fourteen cases. The sands so characterized averaged only eighteen feet thick. Forty-one water sands have an average thickness of fifty-five feet. Seventeen sands reported as containing salt water averaged eighty-four feet thick. The "dead" sands, being dry sands without gas or oil, average seven feet. All of this suggests that the dry and the "dead" sands are small isolated lentils, out of the way of the main routes of percolation. The gas and the oil sands also average much less in thickness than the water bearing sands, only sixteen and seventeen feet, respectively. To some extent this low average is due to the fact that these rocks have not always been penetrated for their whole thickness.

Only ten per cent of all the rocks have been described as to cohesion or hardness. The less frequent use of descriptive terms of this kind is no doubt due to the fact that such qualities are implied in the rock names themselves, soft sandstone being reported as sand and soft shale as clay. "Hard" is evidently a term of relative significance. In the comparatively soft shales and clays in this region an ordinary limestone may be designated as a hard rock.

Some descriptive words have been used which have no other significance than that the strata penetrated consist of layers of sufficiently marked difference in resistance to the drill to be separately noted, but not thick enough to be separately reported. These beds have been described as mixed, broken or shelly.

"Stratified" and "streaks" are words which seem to have been used in the same way. Descriptive terms of this kind have been used for less than one-twentieth part of all the rocks described.

Words denoting texture have been used very rarely in the description, in less than one per cent of all the rocks, evidently for the reason that this quality is implied in the names.

The Underground Section.

The preceding study of the drillers' records of explored formations convinces us, that while some of the individual records are quite inaccurate, still as a whole, and when properly interpreted, the records constitute a fairly correct and full presentation of the underlying formations extending as far down as to the lowest oil and gas bearing strata in both fields. Fortunately some samples have been secured from some of the deepest wells in both fields. These have been found to contain a few fossils which are believed to furnish evidence proving the identity of the deepest producing sands in the two fields, and showing that these sands are in the Cisco formation, as this formation has been defined by Drake for the section of the Pennsylvanian on Colorado River. We have also obtained from Mr. Frank Culinan, manager of The Producers Oil Company in Wichita Falls, a set of thirty-six samples taken from the Halsell Farm well west of Henrietta. This well is 3985 feet deep, and the samples are mostly from the lower half of the well. The drillers' record of the formations in this well will be found in the appendix, well Number 130. The samples submitted were as below:

Description of Samples From the Halsell Well.

	Depth in feet.
Limestone and sand. The limestone contains much organic material in which were noted Rhombopora, crinoid joints, spines of Productus, a minute apex of a gastropod, an ostracod, and Fusulina cylindrica	1450
Limestone, sand and a little shale, Chaetetes noted	1645
Limestone, shale and sand. The shale is calcareous and emits sulphur in a closed tube before ignition	1822

Gray calcareous shale, containing Fusulina, which is abundant, pieces of crinoid spines, and an apex of a tall spired gastropod	1953
Dark bluish-gray shale, with white porous chert with silicified fragments of fossils. A part is sand with grains from one mm. to one-eighth of a mm. in diameter and showing crystalline facets due to secondary growth. On the label of the sample was the note: "First top shell big salt sand." 2120 to	2125
Yellowish-gray sand of fine texture. With this was some dark gray shale, some crinoid fragments and some fragments of white chert	2125
Fine textured yellow sand, with grains from 1-4 to 1-16 mm. in diameter. Some gray shale containing calcareous material	2130
Yellowish sand, gray, of fine texture	2135
Dirty yellowish sand of fine texture	2140
Dull grayish-yellow sand of fine texture	2145
Mostly yellow sand. Some dark gray, or almost black shale, and some organic calcareous fragments. Many fragments of white chert and some of coal. The maximum ingredient of the sand is grains from 1-8 to 1-16 mm. in diameter	2150
Limestone, yellowish, organic, containing white and yellow chert, having a flat and rectangular cleavage. Rhombopora and crinoid stems were noted. One-fourth of the sample is bluish-gray shale. In this was noted a fragment of pyritized woody tissue	2155
Gray shale with some yellowish calcareous organic fragments and some white chert. Fusulina, crinoid stems (one was a half inch in diameter), the apex of a Murchisonia (?) and some thick spines noted	2160
Yellowish crinoidal limestone, with some chert. There was also some dark gray shale. Fusulina present	2165
Gray shale, calcareous, and containing some small flakes of mica	2175
Shale and limestone. The shale is almost black, and breaks into very thin fragments. One fragment was seen to have the impression of a closely ribbed flat shell, some one-half to an inch in diameter, probably an Aviculopecten. One-half of the sample is gray limestone, largely made up of organic fragments. The following fossils were noted: Fusulina (8 fragments), crinoid stems (20), Polypora (?) (2), Rhombopora (1), Retzia (?), very small, (4), Chonetes (1), and a porcellaneous, single apertured foraminifer (?)	2180
Most of the sample is fine yellow sand. The rest is gray shale, and organic yellow sand. In this were noted crinoid stems, fragments of shells, and spines of brachiopods	2185
Dark gray shale, with some thin layers of fine white sand	2185

Gray crinoidal limestone with brachiopod spines, finely tuberculated crinoid fragments, and small pieces of shells	2190
Dark gray shale and yellowish limestone. Fossils noted: Fusulina, crinoid stems, spines of Productus, fragments of brachiopod shells, and some minute tests with a porcellaneous lustre, from one-half to one mm. long, oval, either a foramifer or an ostracod, and fragments of some large shell having a transverse columnar structure	2195
Dark gray shale, minutely micaceous, containing thin and irregular layers of light gray sand of fine texture. Imbedded fragments of leaves were noted	2200
Gray shale containing calcareous fragments, and some shale containing carbonaceous fragments of vegetable origin. Fossils noted: Ostracod, apex of gastropod, bryozoa, crinoid stems, Chaetetes (?), brachiopod spines, a flat coiled small gastropod, a young Pleurotomaria, base of an echinoid spine	2200
Light gray and soft sandstone with grains mostly from one-fourth to one-sixteenth mm. in diameter, very slightly micaceous. There are also thin laminae of coal showing parallel leaf-veins on the flat side	2215
Greenish-gray, slightly micaceous shale, with abundant fragments of Chaetetes (?), spines of Productus, crinoid stems, and other fossils of unknown kinds	2350
About one-half of this sample is a gray calcareous shale, in which are occasional minute shreds of black fragments of vegetation. Most of the rest of the sample is a mixture of calcareous fragments and gray siliceous sand. Fossils noted: a few crinoids joints, pyritized woody fibre, and a piece of a brachiopod valve. From 2958 to	2974
Dark, almost black shale, calcareous in spots and in part minutely micaceous. Some fine sand. The shale disintegrates when washed. Fossils noted: crinoid stems and spines. On the label was written the word "brake." From 2974 to	2976
Dark, bluish-gray shale of fine texture, slightly calcareous, with occasional black indistinct shreds of vegetation and minute flakes of mica. Fossil fragments exceedingly scarce	3015
Black shale showing indistinct impressions of shreds of vegetation on fractured surfaces. There are small imbedded flakes of coaly material. Some shale shows alternate laminae of fine gray sand. All this shale is fissile and sparingly micaceous. One-half, or more, of the sample is yellowish sand, with grains from one-half to one-sixteenth mm. in diameter. There are also some limestone fragments	3330
Dove colored slightly micaceous sandy shale and fine-grained sandstone, in about equal quantities. From 3382 to	3394

The greater part of the sample is black shale, slightly micaceous, splitting into long and slender shoe-peg-like flakes, calcareous. Heated in a closed tube this shale decrepitates, gives strong sulphurous fumes and becomes magnetic. In the sample is also some sand and some calcareous material. Two fragments of coal were noted. On the label is the note: "no water." From 3418 to 3440

Yellowish white sand of mechanical composition about as follows:

Diameter of grain in mm.	Per cent.
½-¼	5
¼-⅛	80
⅛-1-16	15

With the sand are some large fragments of dark calcareous shale of fine texture. On the label was the note: "Middle of sand" 3430

Dark gray shale, with very thin layers of calcareous material. Minute flakes of mica noted, and also some crinoid stems. The shale emits sulphurous odor when heated in a closed tube 3850

Dark gray, almost black shale, of fine texture, very stiff and hard. When rubbed and washed in water, it hardly disintegrates at all, notably less than all the shale above this depth. A part of the sample is calcareous sandstone, light gray, containing a number of green grains (glauconite?). Heated in a closed tube it gives off sulphur fumes and becomes magnetic. Yellow chitinous flakes were noted in the shale. Fossils noted: crinoid stems, cylindric straight spines, fragments showing rectangular cancellations, apparently of organic origin (seen under a 1/6-inch objective), and an undoubted organic structure consisting of fragments of perforate shells of some foramifer like Endothyra. On the label was the word "top." From 3901 to 3904

Shale and organic fragmental limestone as in the preceding sample. Also some black shale and coal among all sizes of fragments. Crinoid stems noted. From 3904 to 3906

Black indurated shale as in the preceding two samples. When heated in a closed tube it emits bitumionus fumes and oil. Fossils noted: crinoid joints and fragments of shells. From 3906 to 3911

THE BEND?

The last fifteen feet in the well are described by the drillers as "gray lime," and above this is 275 feet of dark shale. Three samples of this shale from 3904, 3906 and 3911 feet below the surface are quite different from the other samples of shale from higher levels in the boring. The latter all contain mica scales and are comparatively little indurated. The three lowest samples of shale, representing a thickness of about ten feet, are stiff and disintegrate comparatively slowly when triturated in water. The samples from 3904 to 3911 feet also contain some glauconitic grains. The organic remains in this rock differ from those in the above, consisting of some cylindric straight spines which may be spicules of sponges, fragments of perforate microscopic shells, like the shells of Endothyra and fragments of some organic structure showing an exceedingly fine cancellated texture. An examination of some shale and limestone of the Bend formation, taken near San Saba, shows that the rocks of this formation contain similar perforate foraminiferal shells locally abundant, also occasional glauconitic or green grains, as well as sponge spicules. We therefore venture the suggestion that the deepest rock noted in this well may belong to the Bend formation. As this formation is separated from the Pennsylvanian by an unconformity, the difference in the hardness of the lower shale may also be accounted for on this hypothesis. The presence of coal in the sample at 3906 feet below the surface makes it certain, at any rate, that this part of the well is not below the Bend formation.

THE STRAWN AND THE CANYON.

To designate the precise limits in this well section which separate the recognized divisions of the Pennsylvanian on the Colorado does not seem to be possible. That the Strawn formation as well as the Canyon formation have their equivalents in the Halsell well section there can hardly be any doubt. The great development of dark shales in the lowest thousand feet suggests the presence of an equivalent of the Strawn formation. The facies and the lithologic characters of the rocks in general would be almost sufficient to demonstrate the presence of the Canyon and the Cisco formations. There are calcareous strata in micaceous shales and sandstones. The shales and sandstones contain shreds of coaly vegetation. Chert is also present in some of the samples. In addition to this the samples contained a few fragmentary fossils, which are characteristic of these two formations on the Colorado river, and these prove the greater part of the well section to be Pennsylvanian beyond question, as may be seen from the following:

	Depths below the surface in feet.
Coal, present as fragments	2150, 2215, 3440, 3906
Woody tissue	2155, 2974
Fragments of plant leaves	2200, 2215
Fusulina	1450, 1953, 2160, 2165, 2195
Endothyra	3904, 3906
Sponge spicules	3904, 3906
Chaetetes, sp	1645, 2200, 2350
Crinoid joints	1450, 2165, 2180, 2185, 2190, 2195, 2200 2350, 2974, 2976, 3850, 3911, 3906
Crinoid fragments (spine-like)	1953, 2125, 2190, 2976
Echinoid spine (basal socket)	2200
Fragments of brachiopod shells	2195, 2974
Productus spines, or spines of other brachiopoda	1450, 2160, 2185 2190, 2200, 2350
Retzia (?)	2180
Chonetes, sp	2180
Bryozoa	2200
Rhombopora lepidodendroides	1450, 2155, 2180
Polypora (?) sp	2180
Aviculopecten, sp	2180
Murchisonia, sp	1953, 2160
Gastropod (apex)	1450, 2200
Pleurotomaria (?), sp	2200
Unidentified organic fragments	3904, 3906, 3911

THE CISCO.

It appears probable that the horizon of the Chaffin coal in the Cisco division corresponds to the dark blue shale reported as underlying the gray lime at from 1644 to 1655 feet below the surface in the Halsell boring, and that the Bull Creek coal is the stratigraphic equivalent of what is reported here as dark blue slate lying from 35 to 70 feet below the "gray lime" at from 1420 to 1436 feet below the surface. It will be recalled that Drake reports having observed Fusulina cylindrica about 150 feet above the Bull Creek coal in considerable abundance* and that this is the uppermost part in the Colorado section from which he reports this fossil. Likewise the limestone at 1445 feet below the surface in the Halsell well is found to contain this fossil, and no rock higher up in this well seems to be of a kind in which this fossil is at all likely to occur, excepting the other thin limestone reported at the depth from 1420 to 1436 feet. This part of the Halsell well section is doubtless also the equivalent of the deeper productive oil and gas sands in the two fields under investigation. These consist of shales, limestones and sandstones, which lie at from 1500 to 1700 feet below the surface in the wells near Petrolia and at from 1800 to 2000 feet below the surface in the Electra field. This general correlation seems to be warranted by palaeontologic evidence as well as by evidence based on the lithologic character of the beds explored by drilling.

We have been fortunate in securing a score of samples of drillings from the deeper parts of several wells in the two principal fuel fields and from a few wells in the surrounding country. These have been carefully examined and some of them have been found to contain sufficient fragments of fossils to demonstrate, with at least a high degree of probability, the Cisco age of these beds, irrespective of any inferences based on the known structure or stratigraphic succession in the series of the rocks of this region. Below is a list of all the organic remains which have been noted.

LIST OF FOSSILS FOUND IN SAMPLES OF DRILLINGS FROM DEEP WELLS IN THE HENRIETTA AND ELECTRA FUEL FIELDS AND SURROUNDING COUNTRY.

Bellevue, Clay County.

		Depth in feet.
Crinoid joint.....	Bellevue Oil and Gas Co. 1..........	2030-2038
Productus spine ..	Bellevue Oil and Gas Co. 1..........	2030-2038

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*Geol. Survey of Texas, Fourth Annual Report, Report on the Colorado Coal Field of Texas, Drake and Thompson, p. 413.

Petrolia, Clay County.

Plant spores	Markowitz 1	1700
Plant spores	Markowitz 1	1750
Ammodiscus (flat coiled)	Morgan Jones 1	1818
Chaetetes (?)	Morgan Jones 1	1818
Crinoid joints	Morgan Jones 1	1818
Crinoid spine	Morgan Jones 1	1818

Halsell Farm, Clay County.

Coal	Halsell Farm 1	2150, 2215
Fragments of woody tissue	Halsell Farm 1	2155
Fragments of plant leaves	Halsell Farm 1	2200, 2215
Fusulina cylindrica	Halsell Farm 1	1450, 1953, 2160, 2165, 2195
Chaetetes (?)	Halsell Farm 1	1645, 2350
Crinoid joints	Halsell Farm 1	1450, 2165, 2180, 2185, 2190, 2195, 2200, 2350
Crinoid spines	Halsell Farm 1	1953, 2125
Archeocidaris spine	Halsell Farm 1	2200
Productus spines	Halsell Farm 1	1450, 2160, 2185, 2190, 2195, 2200, 2350
Retzia, sp	Halsell Farm 1	2180
Bryozoa, undet	Halsell Farm 1	2200
Rhombopora lepidodendroides	Halsell Farm 1	1450, 2155, 2180
Polypora, sp	Halsell Farm 1	2180
Murchisonia, sp	Halsell Farm 1	1953, 2160
Pleurotomaria, sp	Halsell Farm 1	2200

Electra, Wichita and Wilbarger Counties.

Coal	Beat 1	1590, 1595
Coal	Rogers 1	1825, 1840, 2550
Ammodiscus (flat coiled)	Rogers 1	2370, 2500, 2535
Fusulina cylindrica	Rogers 1	1825, 1840, 2380, 2395, 2550
Fusulina cylindrica	Waggoner 16	1840, 1846
Sponge spicules	Tate 1	1630
Cyathophyllid	Rogers 1	2300-2395

Electra, Wichita and Wilbarger Counties—continued.

Cyathophyllid	Waggoner 16	1840, 1846
Chaetetes (?)	Rogers 1	2500, 2535
Productus spine	Rogers 1	2380, 2395
Bryozoa, undet	Beat 1	2110, 2140
Bryozoa, undet	Rogers 1	1825, 1840
Fenestella	Waggoner 16	2500, 2535
Ostracods	Rogers 1	1825, 1840
Fish scales	Tate 1	1630

Seven Miles Southwest of Electra.

Leaf impression in shale	Webb 1	1500
Crinoid joint	Webb 1	1500
Rhombopora lepidodendroides	Webb 1	1500

Oklaunion, Wilbarger County.

Ammodiscus (irregularly curving tubes in limestone)	Guffey 1	1402.

Plant remains occur in dark shales, and where profuse, they sometimes appear in the drillings. Impressions of leaves, showing veining, are sometimes to be found. Carbonaceous shreds of woody fibre occur imbedded in sandstone and sandy shale, especially when these are impregnated with pyrite. Spores, noted in one well, are frequently found in coal and in dark carbonaceous shale in the Pennsylvanian elsewhere. A flat coiled Ammodiscus, which was found in several wells here, can almost always be found in the dark shales of the "upper coal measures" in Illinois and Iowa. An irregularly coiled form of this species, present in the Oklaunion well, is locally profuse in limestone in the Missourian, near the uppermost workable coal beds in Iowa. Chaetetes is also known from the upper coal measures in the Central States, and is reported by Drake from several beds in the Canyon division in this state. Fusulina cylindrica, common in the Canyon and in the lower part of the Cisco, disappears with the limestones and marls as we approach the less calcareous beds of the Wichita formation. In the Pennsylvanian of the great Central coal basin this fossil is almost invariably associated with Rhombopora lepidodendroides, spines of Productus, and some peculiar spine-like parts of a crinoid. These latter have somewhat the outline of a phalangeal bone of the human hand. One side is channelled longitudinally and the reverse side is minutely tubercled after a peculiar pattern. The structures are a millimeter long or less. In a great number of samples of fusulina-bearing shales and limestones examined by the senior author of this report, this fossil has nearly always also been present wherever Fusulina occurs. It is enumerated here as "crinoid spine."

THE UPPER LIMIT OF THE CISCO.

The upper limit of the Cisco division in the sections explored by drilling can only be indicated approximately. This limit has not been as yet clearly shown in the nearest outcrops. Cummins and Gordon have indicated it in a general way as extending from the northeast to the southwest across Clay County. Cummins* locates this boundary a little farther south than Gordon.**

There are along this line some sandstones which locally contain streaks of gravel. But neither these sandstones nor any other beds noted along this boundary, can with certainty be identified with any particular horizon in the well section. Nor have any well drillings with fossils been obtained from any stratum lying less than 1400 feet below the surface. We know that the upper 300 feet or more at Electra belong to the Wichita formation, and that the shales and sands penetrated from 1400 to 2000 feet under the surface belong to the Cisco, but how much of the intervening 1200 feet should be allotted to each, we can only guess from the lithologic appearance of the section as made known by the drillers' records.

The general statement can be made that there is a somewhat gradual change from the sediments in the lower parts of this section to those in the upper part. This we think is shown by a general comparison of the percentages of different rocks in a lower, a middle and an upper division of the section and also by a comparison of the combined thicknesses in each hundred feet of some of the more characteristic or leading sediments. Some tables have been worked out for presenting these comparisons. In

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*Second Annual Report of the Geol. Survey of Texas, p. 359 et seq.

**Journal of Geology, XIX, p. 110.

Table I, below, are shown the percentages of each of six kinds of rocks in a lower, a middle, and an upper division in each of thirty-seven wells in the Henrietta field. These three divisions were marked off for each well slightly arbitrarily. The lower division was made to include about 350 feet of strata upward from the lowest productive sand explored. The middle division includes about 500 feet of sediments next above the lower division, and the upper division takes in the remaining 800 to 1000 feet of strata in the upper part of the wells. In Table II the same comparisons are made for twenty-three deep wells in the Electra field. Table III is a combination of Tables I and II.

I.

TABLE SHOWING PERCENTAGES OF DIFFERENT ROCKS IN THREE DIVISIONS OF THE SECTIONS OF THIRTY-SEVEN WELLS IN THE HENRIETTA FIELD.

	Gravel.	Sand.	Shale.	Lime-stone.	Gypsum, etc.	Undetermined.
Upper division	Trace	19	64	Trace	1	16
Middle division	Trace	25	58	Trace		17
Lower division		16	75	.5	2	6

II.

TABLE SHOWING PERCENTAGES OF DIFFERENT ROCKS IN THREE DIVISIONS OF THE SECTIONS OF TWENTY-THREE WELLS IN THE ELECTRA FIELD.

	Gravel.	Sand.	Shale.	Lime-stone.	Gypsum, etc.	Undetermined.
Upper division	1	11	71	3	Trace	14
Middle division		16	70	3	Trace	12
Lower division		11	66	10	1	10

III.

TABLE SHOWING PERCENTAGES OF DIFFERENT ROCKS IN THREE DIVISIONS OF THE SECTIONS OF THE SIXTY WELLS OF BOTH FIELDS.

	Gravel.	Sand.	Shale.	Lime-stone.	Gypsum, etc.	Undetermined.
Upper division	Trace	16	67	1	3	15
Middle division	Trace	21	62	1	1	15
Lower divison		14	71	4	2	8

The general parallelism in the changes shown in the two fields corroborates the conclusion already drawn from other evidence, that the Electra section, excepting its upper part, is the equivalent of the Petrolia section. It has been shown that the uppermost 200 or 300 feet of sediments at Electra are probably absent in the Petrolia section. This is also indicated in the two first tables, the upper division at Electra having a slightly higher per cent of shale and a smaller per cent of sand, owing to the greater prevalence of shale in these upper beds, which are not so largely represented at Petrolia. The greater development of limestone at Electra is the most notable difference in the two sections, but this change is demanded by what is known concerning the geographical conditions attendant on the deposition of these sediments. Electra was farther away from the Cisco-Albany land than Petrolia, the shore being somewhere to the east and the open sea to the west. Hence more limestone is to be expected at Electra.

The change upward in the section is even better shown by the disapparance of black and dark blue shales, and by the interrupted and less and less frequent occurrence of some more than usually white clays reported variously as "white clay" or shale, "chalk," "putty," "talc," or "soapstone." It is also evident from the slightly irregular but progressive increase in the quantity of red clays and shales. For the purpose of seeing these changes clearly, notes were made of the number and thickness of such beds, for each hundred feet below the surface in twenty deep wells in each of the two fuel fields.

TABLE SHOWING THE NUMBER AND COMBINED THICKNESS OF WHITE CLAYS AND DARK CLAYS FOR EACH HUNDRED FEET IN TWENTY WELLS NEAR PETROLIA AND IN TWENTY WELLS IN THE ELECTRA FIELD.

Feet below surface. From—to	Twenty wells near Petrolia.				Twenty wells near Electra.			
	Number of beds of clay.		Combined thickness of beds of clay, in feet.		Number of beds of clay.		Combined thickness of beds of clay, in feet.	
	White.	Dark.	White.	Dark.	White.	Dark.	White.	Dark.
0—100	0	0	0	0	0	0	0	0
100—200	0	0	0	0	0	0	0	0
200—300	0	0	0	0	0	0	0	0
300—400	0	0	0	0	0	0	0	0
400—500	0	0	0	0	0	0	0	0
500—600	1	0	25	0	4	0	97	0
600—700	2	0	31	0	1	0	25	0
700—800	6	0	73	0	2	0	14	0
800—900	5	0	125	0	1	0	59	0
900—1000	1	1	17	59	4	2	29	86
1000—1100	8	2	126	86	4	1	57	5
1100—1200	4	4	200	96	2	2	0	15
1200—1300	3	4	50	184	3	2	14	25
1300—1400	5	7	122	146	4	1	64	40
1400—1500	2	20	39	520	4	1	52	25
1500—1600	12	10	172	134	4	2	18	30
1600—1700	9	9	100	129	2	0	19	0
1700—1800	2	6	93	196	10	6	25	100
1800—1900	1	6	20	58	13	10	12	207
1900—2000	-------	-------	-------	-------	4	3	6	44
0—2000	61	69	1093	1608	62	30	491	577

It is seen that the beds of white clay are most numerous at from 1500 to 1600 feet below the surface in Petrolia and that the dark shales are most frequent at the depth of from 1400 to 1500 feet. In the Electra fields these shales are both most numerous at from 1700 to 1900 feet. We may say that the zone of the greatest frequency of dark and white shales and clays is from 1400 to 1600 feet below the surface at Petrolia, and is from 1700 to 1900 feet below the surface at Electra. The dark shales extend up to 900 feet below the surface in both fields and the white clays have been first encountered at from 500 to 600 feet in both fields. These changes are, on the whole, parallel in the two sections and no doubt they can be regarded as marking out, roughly, parts of the sections which are to be correlated in the two fields. As we have already seen from other evidence, the beds lying from 1700 to 1900 feet below the surface at Electra, have their equivalent from 200 to 300 feet nearer the surface at Petrolia. As was found in the case of the exposed limestones, so we find here a horizontal change in the sediments, especially in the development of the dark boggy shales which most notably decrease in the seaward direction. The disappearance of the dark or black and the white clays appears to be the most marked feature of lithologic change in the upper 1400 feet of the two sections. This disappearance takes place in the beds from 500 to 1000 feet below the surface. At the present time it would seem unprofitable to attempt to more closely limit the boundary between the Cisco and the Wichita on the basis of general lithologic characters. The very gradual change from the undoubted Cisco beds to undoubted Wichita beds is even more apparent from a study of the frequency and thickness of red clays. There is a quite uniform increase in the amount of red argillites from the deepest part of the wells up to the surface. This is shown in the following table, which is based on the records of twenty wells in the Electra field and twenty wells near Petrolia.

TABLE SHOWING RELATIVE FREQUENCY AND TOTAL AMOUNTS OF RED AND BROWN CLAY NOTED IN EACH HUNDRED FEET BELOW THE SURFACE IN TWENTY WELLS IN THE ELECTRA FIELD AND IN TWENTY WELLS NEAR PETROLIA.

Feet below surface.	Petrolia.		Electra.	
	Number of beds.	Total thickness.	Number of beds.	Total thickness.
0— 100	42	1304	26	1238
100— 200	29	1084	22	1148
200— 300	25	1026	26	935
300— 400	26	890	29	939
400— 500	24	647	23	830
500— 600	16	581	27	551
600— 700	24	658	24	722
700— 800	21	586	29	658
800— 900	14	446	35	827
900—1000	18	448	21	862
1000—1100	15	454	19	549
1100—1200	13	452	16	526
1200—1300	12	231	13	472
1300—1400	6	261	22	303
1400—1500	10	201	15	415
1500—1600	5	119	16	346
1600—1700	10	71	17	285
0—1700	316	9409	379	11,606

It may be worth the while to note, that if the upper limit of the Cisco be near the lower extreme which we have indicated, the oil sands at about 750 feet below the surface near Petrolia and at about 1000 feet in the Electra field would be at about the same level in the general section as the thin coal seams noted in the Indian Creek bed on the Colorado River.

SUMMARY OF CORRELATIONS.

To sum up the essential correlations for these fuel fields: The Bend formation is perhaps present near 3900 feet below the surface in the southeast part of the area studied. From about 3900 to 1800 feet below the surface the bed rock is an equivalent of the lower half of the Cisco, the Canyon and probably the Strawn divisions on the Colorado River. The Bull Creek coal and its associated dark shales and other beds are probably the stratigraphic equivalents of the dark shales and productive sands lying at from 1500 to 1800 feet below the surface in the wells near Petrolia and at from 1700 to 1900 feet below the surface in the Electra wells. Some thin coal seams noted in the lower part of the Albany sediments in the Colorado River basin may be the stratigraphic equivalents of the zone producing some oil at about 750 feet below the surface in a part of the field at Pe-

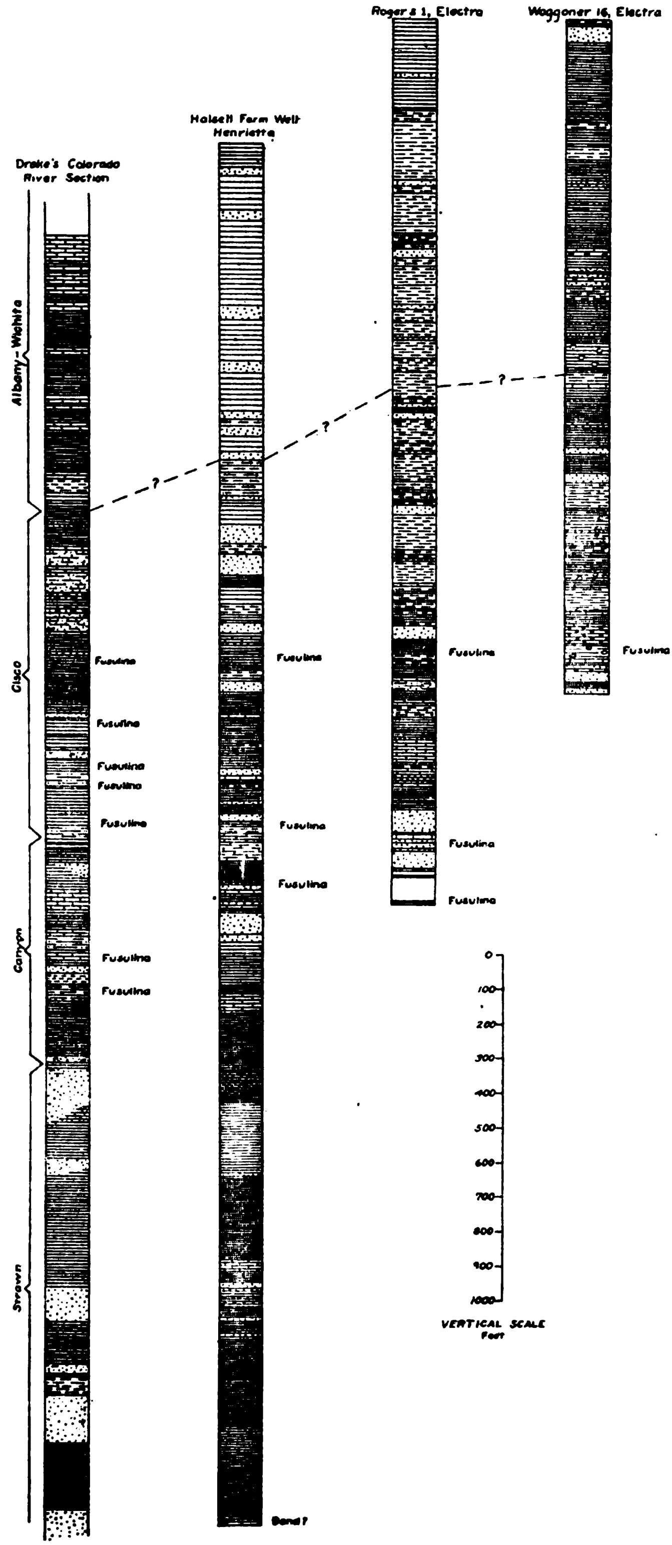

FIG. 8. General correlation of Drake's Colorado River Section with sections of three wells in the Henrietta and Electra Fuel Fields.

trolia and of the productive sands at about 1000 feet below the surface near Electra.

We have shown that it is more than likely that the gas-bearing sands which lie from 550 to 700 feet below sea level in the Henrietta field are at the same horizon in the general section as the oil-bearing beds in the Electra field which lie some 200 or 300 feet deeper, forty miles farther west. We have presented three groups of facts which bear out this conclusion. The Beaverburk limestone shows that the Wichita beds lie practically horizontal on an east and west line for about fifteen miles. Combining ninety observations made on dips in the area between Electra and Petrolia we have found that if these dips be taken to represent the general structure of the terranes between these two points, the beds lie nearly horizontal. Comparing the strata explored in the two fuel fields we have also found that there is in the formations themselves a resemblance which confirms our belief that the deep productive sands in the two fields, as well as the upper sands, are to be correlated with each other.

Fortunately, however, we are not limited to evidence which makes our conclusions on this point almost certain, but still questionable. There is other evidence, which in connection with that already mentioned, must be fairly conclusive, even if the basis of facts involved is somewhat slender. This consists in the presence in the deeper oil bearing deposits in both fields of a few identical fossils. The finding of these fossils also enables us to roughly correlate the underground section in this region with the general section of the Pennsylvanian in Texas.

THE ORIGIN OF THE OIL AND GAS.

It does not seem necessary to here rehearse the various theories advanced to explain the origin of petroleum and natural gas in various parts of the world. The evidence in these fields appears to us decidedly to support the view that the natural hydrocarbons here are derived from organic material, which was an original ingredient in the sediments of the formations where oil and gas are now found, in the shales and clays containing oil sands and gas sands. The present writers are not at all convinced that this statement should be limited so as to apply only to shales which are not of red color. The red shales occasionally show some features which suggest that it may not be safe to conclude that the mud of these deposits was not originally, at least while yet in suspension and immediately upon deposition, very much like the mud in the shales which are now gray, bluish-gray, or quite dark in color. We are not ready to express any opinion on the possibility of much of the red clays having been once gray or blue clays. But it is quite evident from the drillers' records of well sections that red clay frequently runs into gray clay horizontally. Some field appearances in the Wichita formation indicate that the quantity of calcareous or other alkaline material present in the clays, or the proximity of such material, determines to some extent the color of the clays. There is nearly always some blue or gray shale under limestones, or even under bands of calcareous concretions. There are frequently gray clays under sandstones, especially when these have a calcareous matrix. There are occasionally blotched, red and gray shales in which the distribution of these colors clearly shows no relation to the sedimentary structure. Furthermore, instances of change in color have been noted which clearly imply a relation of the present colors to the slow creep of rock moisture and its solvents, as affected by texture of the rock and by the direction of what we might call its capillary grain. See Plate XXIII, C.

Nor are we quite convinced that animal and plant life was always less vigorous during the accumulation of the red shales in the upper part of this section than in the time of the making of the Cisco beds. Animal remains are profuse in the two limestones of the Wichita formations. Fishes must have been abundant in a sea where their scales were washed into sorted sizes, forming layers three to six inches thick. Amphibians must have had a sufficiency of food, at a time when leg bones of dozens of individuals of their tribe were sorted by the waves and washed up on a few square yards of the shore. It does not appear that a theory involving an exotic origin is needed to account for the presence of either oil or gas in the sands of the upper 1000 feet of the section, much less for their presence in the lower part of the section. In fact, organic material is yet present in the thin limestones and blue shales of the Wichita formation in sufficient quantity to give readily noticeable bituminous odors when ignited. The oil and gas are so closely associated with organic remains that an extraneous origin appears quite improbable.

The original presence of organic material in the shales of the Cisco division in sufficient quantities to furnish all the oil and gas in these fields, however rich, is really beyond question. There are several hundred feet of dark and bituminous shales above and below the producing sands, and at least one or two hundred feet of very dark, almost black, shales in close proximity to the oil-bearing sands. On heating these dark shales in a closed tube, they give, almost invariably, not only sulphur fumes, but also fumes of bitumens and of ammonia. The fumes of ammonia are strong enough to give a stinging odor. Ammonia was specially noticeable in dark shale from 2262 feet in the Woodruff No. 2 well and from 2550 feet in Rogers No. 1 well at Electra, and from 1750 feet in the Markowitz No. 1 well, and from 1818 feet in the Morgan Jones No. 1 well, at Petrolia. Some quantitative analyses on these ingredients of the shale have been made by Mr. S. H. Worrell. A sample of shale from 2262 feet below the surface in the Woodruff well No. 2, at Electra, he found to contain 1.05 per cent of nitrogen, equal to 1.19 per cent of ammonia, and another sample of shale from 1818 feet below the surface in the Morgan Jones No. 1 well at Petrolia yielded 1.10 per cent of nitrogen, equal to 1.25 per cent of ammonia. Mr. Worrell has also made an estimate of the quantity of oil in a mixed sample of brown and black shale from the Markowitz No. 1 well. From 200 grains of the material he obtained "5 c. c. of water and about one-half c. c. of oil having an aromatic odor." Red shale constituting about half of the mixture, this would indicate that the black shale contains, at the least, a gallon of oil to the ton at the present time.

It would seem that we have in these analyses a suggestion, if not really a proof, that some of the organic material originally in the shale, has, by a natural distillation, formed the hydrocarbons now held in some of the included sands, leaving a high residue of ammonia in the shale. For the shale which here contains less than a half per cent of oil contains more than one per cent of ammonia. The organic material in these shales resembles that in the oil shales in Scotland, in that it is not present in the shales in the form of bitumen. Mr. Worrell found that it was not soluble in gasoline. Comparing this Cisco material with the Scottish shales as to proportionate contents of oil and ammonia, we find the former has a relatively much higher per cent of ammonia. The average yield of the Scottish shales is about three parts of oil to one part of ammonium sulphate.* In the shale-oil factories in Scotland, a shale like this from the Markowitz well would no doubt be classified as "spent shale," a shale which has by natural distillation lost a part of its oil content.

The high nitrogenous content of these shales, as well as the fact that the oils in these fields have a paraffine base, suggests that the organic material from which the hydrocarbons are derived was of animal rather than of plant origin, as the larger percentage of proteids and albuminoids in animal tissue would account for the large quantity of nitrogenous compounds in the shale. There are, however, also oil-yielding plants, containing much protein substance, as has been shown by Phillips.†

Sedimentary Deposition of Oil.

The subject of the formation of sedimentary deposits containing oil has lately been investigated by Murray Stuart, of the Geological Survey of India. Mr. Stuart has published a paper in the Records of the Geological Survey of India, and this has recently been reviewed by Dr. David White in one of our American journals.‡ The discussion of the subject is timely and Dr. White's review will no doubt interest students of American oil fields. Mr. Stuart has shown that minute droplets of oil can become imbedded in sediments of fine texture by adhering to the particles forming such sediments and sinking with them to the bottom of the basin in which the sediments accumulate. It is an eminently lucid statement of a simple and, as it appears, very general process. Just for this reason his sedimentation theory seems to us an eminently credible one. Organic material is seldom, if ever, wholly absent from fine sediment of any age. A theory accounting for the presence of organic material in sedimentary rocks should explain the quite general presence of small quantities of organic material, as well as the exceptional abundance of organic products in some particular strata. Excepting, perhaps, dead seas whose water has been evaporated down to brine, all waters of all ages have contained the more or less disintegrated remains of the life of the day. This life may have been more luxuriant at some times than at others, and more profuse in some localities than in others. A study of the origin of petroleum and natural gas is not merely an inquiry into the exceptional conditions causing abnormally large accumulations of hydrocarbon compounds in small areas of particular strata.

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*Petroleum Mining. A. Beebe Thompson, pp. 118, 119.

†Bulletin of the University of Texas, No. 5. Texas Petroleum, W. B. Phillips, p. 20.

‡Economic Geology, Jan., 1912, pp. 91-95.

Productive Sands and Coal Horizons.

Returning to the consideration of the Electra and the Henrietta (Petrolia) fuel fields, we find the producing sands lying in the sediments of the Pennsylvanian age, and extending up into the Wichita division, which has been classified as Permian. At no age in the earth's past history is there evidence of a more luxurious vegetation, more widely distributed, than at the time of the forming of the sediments of the Pennsylvanian. Making closer comparisons, we find that the oil-bearing beds correspond to horizons in the Pennsylvanian section which are characterized by beds of coal, proving the contemporaneous existence of profuse vegetation on lands not far distant. This vegetation, so near, indicates contemporaneous favorable conditions for a marine flora and fauna, the remains of which no doubt would enrich the bituminous contents of the finer sediments of the period. Under such conditions local and exceptionally rich accumulations of bituminous material in these formations would be the almost unavoidable result, dependent upon the later slow segregation and tardy interstitial translatory movements of the fluids adjusting themselves continuously to the progressive development of retaining structures, in which they are held at the present time.

THE OIL AND GAS SANDS.

The oil and gas in these fields are contained in sandstones. In the Electra field some little oil has been noted in a few wells in a limestone lying about 90 feet below the surface. This is probably the Beaverburk limestone. From one or two other wells oily shale has been reported. Barring these exceptional instances, the oil and gas in both fields have been obtained from strata of sandstones measuring from a few inches to twenty or thirty feet in thickness. In most wells these have been penetrated for their whole thickness, in others they have been merely entered. Some sands are in single strata, others are in several, separated by thin seams or layers of shale. A review of the several oil or gas sands in both fields shows that only in two instances have any such sands exceeded 40 feet in thickness. The remaining 450 sands in which oil or gas have been noted average nearly twelve feet in thickness, and are distributed among different thicknesses in the two fields as follows:

TABLE SHOWING NUMBER OF OIL AND GAS SANDS OF DIFFERENT THICKNESSES IN THE HENRIETTA (PETROLIA) AND ELECTRA FIELDS NOTED IN SIXTY WELLS IN EACH FIELD.

Limits of thickness in feet.	1—5	6—10	11—15	16—20	21—25	26—30	31—35	36—40
Henrietta—								
Middle and upper sands	13	10	6	3	2	2	-------	-------
Deep sands	23	27	9	8	4	3	3	-------
Stray sands	16	13	10	4	6	1	1	1
Electra—								
Middle and upper sands	19	25	19	27	23	13	3	2
Deep sands	12	10	6	3	3	2	1	-------
Stray sands	28	30	21	15	14	6	1	2
All sands in both fields	111	115	71	60	52	27	9	5

It will be seen that the sands are quite variable in thickness and comparatively thin. They also are quite irregular as to the level at which they lie in the general section. Even if we make allowance for considerable latitude in the making of some measurements, it is evident that many of the sands in some wells have no equivalents in other wells. Nevertheless it appears that the oil and gas sands fall into some well defined groups, and some other groups which are not so well defined. We may designate three groups which are fairly well defined, as the Deep Group, the Middle Group, and the Shallow Group. We would include in the Deep Group the sands lying deeper than 1400 feet below the surface in the Henrietta (Petrolia) field and deeper than 1700 feet in the Electra field. In the Middle Group we would include the sands that cluster around 720 feet below the surface in the Henrietta field, and around 1000 feet in the Electra field. In the Shallow Group we would include the sands lying above 400 feet below the surface in parts of the Henrietta field and 700 feet in the Electra field.

The records of some wells show that there are places in both fields where even the best developed sands are absent. The separate members of the groups are not continuous everywhere, even within the limits of the same field. But it clearly appears that each group is present in both fields.

The Deep Group Sands.

In the Henrietta field the Deep Group clearly consists of two levels of sands, about one hundred feet apart vertically. A well defined dome here easily accounts for differences in reported measurements of at least as much as two hundred feet in the same sand, and thus enables us to recognize the two principal members of this group. The lower of these two sands has been the more reliable as a producer, and this we would call the Lockridge sand, as it was first tapped in Well No. 1 on the Lockridge farm.

The Deep Group at Electra is much less clearly defined, and the various sands thus generally designated are spread through a greater vertical distance. No such structure as at Petrolia is sufficiently evident to explain the differences and we are forced to the conclusion that the oil sands here become more numerous or more broken, possibly both. Thus, pay sands are reported at twenty-five depths between 1750 feet and 1960 feet below surface. Certain of these sands, which from a comparison of all the available records we believe are most regularly developed, are reported five times within a few feet on either side of 750 feet below sea level, five times within a few feet on either side of 695 feet below sea level, and seven times within a few feet on either side of 575 feet below sea level, these distances corresponding to depths below surface of about 1945 feet, 1890 feet and 1825 feet respectively. The two lower of these sands seem best developed in the center of the field, where the surface elevation averages about 1195 feet above sea level, while the upper sand shows best in the wells on the Waggoner tract south of the railroad, where the surface elevation averages about 1250 feet above sea level. As yet no definite correlation of these sands is as clear as at Petrolia, but we believe that two levels, similar to those at Petrolia, will be more clearly outlined with progress in the development of the field.

The Middle Group Sands.

In the Petrolia field, there are again two fairly well defined oil sands comprising a group, though there are several stray sands within the limits set. These well defined sands occur only in a limited portion of the field, which may be said to be restricted to the crest of the dome, and lie at depths close to 660 feet and 720 feet below the surface. These also consist of a basal sand, not penetrated in all the wells, a regularly overlying sand about sixty feet above, and one or two stray sands scattered through the range of the group.

In the Electra field the Middle sands are the largest producers. They are in this field more regularly and more largely developed than in Clay County; and occur in all portions of the field. In most wells they appear as two sands, separated by from forty to one hundred feet of shale, and occurring with greatest frequency near 955 feet and 1040 feet below surface. In some wells there is also a sand at about 820 feet. These sands are not everywhere continuous, but frequently split up into two or three thin sands. There are also stray sands that do not seem to be referable to any of those mentioned.

The Shallow Group Sands.

The productive sands of the Shallow Group are much more irregularly scattered than those of either the Deep or Middle Groups. The area of pay wells in these sands in the Henrietta field, while more extensive than in the case of the Middle Sands, is still closely restricted, and has so far been shown to follow the crest of the local uplift. A comparison of the number of sand beds for each successive ten feet upward from the basal sand of the Middle Group in some fifty wells shows marked increases at about 460 feet and 370 feet above this basal sand in the Henrietta field. This would indicate the existence of sandy horizons. These sands correspond to what are known as the 260-foot sand and the 350-foot sand in the center of the Henrietta field. In addition to these, there are numerous stray sands.

In the Electra field, these Shallow sands have only a small development. The one most regularly reported lies about 510 feet above the basal sand of the Middle Group, but this sand is not reported from all wells, nor is it generally oil-bearing when reported. It is generally referred to in the field as the 530-foot sand.

Irregular Development of Sands.

The position of the sands in the entire section suggests that they are ancient sand bars and perhaps beach sands, built up, washed away, rebuilt, and finally buried under accumulating argillaceous sediments, during a long period of more or less gently changing geographic conditions, involving, on the whole, a progressive sinking of the shoreland and the adjacent bottom of the sea. Sands connected in one place may in another place be separated. Closely contiguous sands may be wholly separate. Sands clearly interrupted at some point may be connected by some devious circuit in an unknown direction.

Conditions like these are plainly suggested by many cases of apparently abnormal vertical distribution of water, gas and oil in the same well, and in sands which are not far apart, and even quite contiguous and apparently confluous. This will be evident from the following observed successive vertical occurrences of oil, gas, and water in wells (a, b, c, etc.), in different parts of the two fields.

OBSERVED VERTICAL SUCCESSIONS OF WATER, OIL AND GAS IN CLOSE LYING SANDS.

PETROLIA.

(a)	(b)	(c)	(d)	(e)	(f)
Gas	Gas	Gas	Gas	Gas	Gas
Gas, oil	Gas	Gas	Gas	Gas	Gas
Oil	Oil	Oil	Oil	Oil	Oil
		Oil	Oil	Oil	Oil
			Oil	Oil, water	Oil

(g)	(h)	(i)	(j)	(k)	(l)
Gas	Gas	Gas	Gas	Gas	Gas
Oil	Oil	Oil	Oil	Gas	Oil
Gas	Gas, oil	Gas	Gas	Gas	Gas
Oil			Gas	Oil	Gas

ELECTRA.

(m)	(n)	(o)	(p)	(q)	(r)
Gas	Gas	Oil, gas	Oil	Oil	Water
Gas	Oil	Oil	Gas	Oil, gas	Oil
		Oil	Oil		

Texture of the Productive Sands.

The texture of the oil and gas yielding sands is usually moderately fine, but coarse sands have also been encountered. The following table of the mechanical composition of some productive sands is believed to be representative for these fields:

TABLE SHOWING THE COARSENESS OF GRAIN OF NINE OIL AND GAS SANDS IN THE HENRIETTA (PETROLIA) AND THE ELECTRA FUEL FIELDS. FIGURES GIVE PERCENTAGES OF WEIGHT OF EACH GRADE OF COARSENESS OF SAND TO TOTAL SAMPLE.

Diameter of grains in millimeters.	Stringer 8 960 ft.	Skinner 4 1000 ft.	Stringer 9 970 ft.	Panhandle 3 1120 ft.	Skinner 1 1009 ft.	Lone Star 1 1684 ft.	McBurney 1 814 ft.	Putnam 16 1020 ft.	Waggoner 12 1800 ft.	Panhandle 3 1510 ft.	Bickley 1 880 ft.	Panhandle 3 1610 ft.
2—1	19	1	tr.	tr.		tr.						
1—½	43	7	5	5		tr.						
½—¼	26	52	15	14	28	19	9	tr.	tr.	tr.	3	tr.
¼—⅛	11	33	60	28	52	75	81	73	72	40	40	23
⅛—1/16	1	7	20	40	20	6	5	18	21	30	34	50
1/16—1/32				13			2	9	7	10	23	25
1/32—1/64												2

THE RETAINING STRUCTURES.

We have found that the dark shale, especially in the lower half of the section, contains much bituminous material. On account of the closeness of the texture of the shale, any oil or gas which this may contain can not be recovered by drilling into this. It is clear that the oil or gas which is now found in the sand has been derived from contiguous shales, whether overlying or underlying the sands, by some exceedingly slow secular transfusion. The sands are therefore the first essential structures necessary for the accumulation of oil or gas in available quantities, as sand rock alone is sufficiently porous to contain any considerable quantity of bitumens.

In any system of rocks, ground water is almost universally present, partly perhaps as an original ingredient, but more generally as a result of rainfall, and consequent secular movement through minute porosities in the terranes. As the ground water is heavier than oil, it will tend in the long run to replace this lighter fluid and cause it to move in any direction that is open. The oil is made to float, as it were, on the heavier fluid. It is apparent that a resulting slow movement of the oil or gas will follow, especially in the relatively more open beds. This will proceed in a direction opposite to the dip, obliquely upward. In porous strata of this kind rising to the surface of the earth, this slow migration of the oil may ultimately result in its entire replacement by the ground water, and in the complete outflow of bituminous materials along the line of outcrops of the porous rock, causing what are known as "oil seeps." It is quite possible that extensive oil accumulations in the Pennsylvanian rocks in the north central part of the State have in this way escaped from the sands which once held them.

It is evident that the oil and gas which is now being recovered in the fields at Petrolia and Electra is confined in the ground by structures which have prevented their replacement by the ground water in the manner described. We have shown that in the country lying between Petrolia and Electra the strata lie practically horizontal. We have also shown that the strata are affected by flexures, which cause them to dip in various directions at low angles. The horizontal position of the terranes in this field is the primary structure which has been the cause of preventing the bitumens from escaping under the pressure of the ground water. But it is evident that no great quantity of oil or gas can be held under the perfectly flat surface of a horizontal layer of shale. This flat condition seems to be the general structure for the region as a whole, and we believe it explains the frequent and very general existence of very small quantities of oil, or of "oil shows," in the wildcat wells.

The Petrolia Flexure.

The local accumulation of oil and gas in paying quantities in these rocks seems to have required here, as elsewhere, pronounced flexures, resulting in inverted basin-like, trough-like folds in heavy layers of relatively impervious shales. Such folds are known as domes or anticlines, according as their shape is more or less circular or elongated. The Petrolia field is a clear case of such a fold. This fold may be said to be an irregularly elongated dome, some 200 feet high and having an area of six or seven square miles. Judging by the deep explorations which have been made up to the present time, it is about twice as long as broad, and the longer axis extends in a west-northwest and east-southeast direction. The structure is clearly shown in the dips of the exposed rocks of the surrounding country, as indicated by the arrows on Plate I. The highest point in the fold lies about one and one-half miles southeast of Petrolia, and another smaller accentuation on the fold apparently exists one and one-half miles still farther southeast. See Plates II, IV, V, VI and VII.

Structure of the Electra Field.

At Electra the structure is at first sight quite perplexing. The sands of the Middle Group, which produce most of the oil in this field, lie essentially horizontal within the area of the greatest production in the present field. See Plates III, and VIII-XII. These sands even show a slight curvature downward into one or two very shallow basins. This is an unexpected condition. The horizontal position of the formations is also evident from the surface outcrops. The strata lie nearly flat over an area of several square miles, extending from one-half mile south of the railroad to at least one mile north of the railroad. Nor is any considerable dip known on a line extending three miles east and west through the centre of the field. But an examination of the outcrops south and southwest from Electra show a persistent dip to the southwest for several miles. The strata dip continuously southward along Bluff Creek as far south as to within a mile of Beaver Creek at a rate which we estimate to be near 15 feet to the mile. Whether there is a corresponding dip to the north on the north side of the field we failed to make out. In this direction exposures are indecisive. But it will be seen that most of the dips noted in the country north from Electra and Iowa Park, as far as to Red River, are to the north, northeast, or east. The observations are too few to prove a general dip in that direction. Some other doubtful evidence of such a dip was noted in the occurrence of a concretionary sandstone at a low elevation, a mile and a half from Red River on China Creek. This sandstone resembles another sandstone lying at a considerably higher elevation on a hill about four miles southeast of Electra. Compare A and B, Plate XXIII. But correlations based on resemblances in sandstones are of little value. What can be said without peradventure of doubt about this field is that it is situated either on the crest of a very wide and flat anticline, or else close to the south edge of a structural terrace, where flat-lying beds soon begin to dip to the south. In either case, the smaller basin-like depressions noted in some of the wells for parts of the field are to be regarded as minor details on a larger structure. They may be due to deformation, but it is quite possible that such slight depressions as have been noted in the Electra field are original in the bedding of these sands. They may have been laid down on the bottom of a basin with even greater downward flexure than these sands show at the present time. This oil field, therefore, may very well be on the crest of an incline which, however, is so flat that the upward folding has not sufficed to quite straighten, or reverse, the original downward curvature of the small basin-like depressions in which the sands were deposited.

Structure of the Sands as Related to Oil and Gas Contents.

Some of the operators in the Henrietta (Petrolia) field are of the opinion that the gas is replenished in some of the sands now tapped, by filtering into these through limited passages connecting with other sands. It appear sthat as the gas is tapped, pressure is lowered, but on shutting the wells down the pressure rises again, as if the supply in the tapped sand were again replenished somewhere from the outside of its own body. From conditions already described it seems quite probable that such transfer may take place from one body of sand to another, where the two are imperfectly separated by sediments of closer texture than sand but not close enough to effectually shut off the connection. Phenomena of this kind may very well be due to local thinning on an elongated bar-like body of sand.

Fractionation By Filtration.

In a study of the diffusion of crude petroleum through fuller's earth recently made by Gilpin and Bransky* of the United States Geological Survey, these authors have shown that when crude petroleum diffuses upward through a tube packed with fuller's earth, a fractionation of the oil occurs. The oil that is afterward recovered (by the method used by these authors) from the earth from the top of the tube possesses a lower specific gravity than the oil obtained from the earth at the bottom of the tube. They also found that when a solution of benzene and of paraffine is allowed to diffuse upward through a tube packed with fuller's earth, the benzene tends to collect in the lower part of the tube, and the paraffine oil in the upper part.

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*The Diffusion of Crude Petroleum through Fuller's Earth, Bulletin 475, U. S. Geological Survey, Washington, D. C.

Several circumstances in these fuel fields are strongly suggestive of the effective operation of some such process of fractionation by diffusion on an extensive scale. The irregular development of the sands is the suggestive geological feature. The ammoniacal residue left in the lower dark shales, as noted in several wells, indicates extensive disintegration of organic compounds and no doubt contemporaneous transfusion of the lighter material through the containing sediments. It seems that in their composition the Electra and the Petrolia oils would illustrate the results of this process operating under natural conditions, for these oils have a paraffine base and contain an unusually high per cent of benzene and kerosene. It is also worth noting in this connection that an oil has been found in Panhandle No. 1 at Petrolia at a depth of 1122 feet, which has a gravity of .72 and contains a notably higher per cent of gasoline than any of the other oils of these fields. This oil came from what we would call a stray sand.

PROSPECTIVE DEVELOPMENT.

Our observations on dips show, as we think, that the general trend of the prevailing structures in this region is from west-northwest to east-southeast. This conclusion is strengthened by the fact that the Petrolia uplift has its major axis extending in about the same direction. The fact that the dips we found in different parts of Wichita and Clay Counties are numerically about equally distributed in both directions away from this hypothetical axis, indicates that the structures which are present are folds, anticlines and synclines, or elongated domes, rather than faults. Dips in faulted formations usually all have the same direction.

At Petrolia the surface dips indicate that the anticlinal structure extends some distance beyond the proven productive area.

This limitation of the productive area may be due to either one of two conditions. The sands may lie in belts which cross the trend of the uplift, and hence run out to the northwest and to the southeast. Explorations are too few to permit anything but speculations as to the form of the deep sands. It appears that this field marks an accentuated tract on a much longer structure. It may very well be that gas and oil have accumulated mostly only in this highest part of the anticline, having drained away upward under the pressure of the ground water from the lower parts of the fold, following its axis lengthwise. It may be that other fields can be found on structures having the same general trend as these have, whether on the same or on other lines. The extreme gentleness of the Electra structure and the indicated irregularity of the uplift at Petrolia make it very likely that existing structures will be difficult to follow, but a knowledge of their general trend should be a distinct advantage in tracing their indistinct outlines.

The existence of oil or gas depends in the first place on the nature of the sediments. Earlier studies of the stratigraphy of the oil-bearing formations in North Texas show that the Albany beds undergo considerable changes southward, becoming to a great extent limestones interbedded with shale. With such a change prospects for oil may become more problematic. How far the conditions associated with the occurrence of oil and gas in this field will obtain in the several directions, east, south and west is only partially known. The formations rise to the eastward. They probably gradually go down to the west. To the south the elevation of the strata is about the same as here for two or three hundred miles. But the nature of the beds changes in this direction. Whether there is a similar change westward is not known. It is indicated by the relative increase in reported limestones in the Electra wells as compared with the wells near Petrolia. The general conditions of stratigraphy and structure certainly do not change very materially in fifty miles in any direction in the territory on the south side of Red River, and it is quite natural that this area should be most actively prospected at the present time.

The features characteristic of the Electra field are the general horizontal attitude of the formations, the irregularity of the small dips which exist and of the sandstone bodies themselves. These circumstances all suggest that other places than the two fields immediately under investigation may exist, where oil and gas have accumulated in quantities commensurate with the production in the fields already known.

Upland Gravels.

A conglomerate which has been variously classified as of Pleistocene or of late Tertiary age should perhaps be noted, for the reason that it has been mistaken by some for being a part of the terranes whose structure determines the oil accumulations in these fields.

This conglomerate is of so late an origin that its distribution is clearly to some extent related to the topography developed by the present drainage. It lies high up 'on the divides and low down in the larger valleys, and can therefore not have the remotest connection with the structures of the Palaeözoic series. It was noted on some of the highest hills on the divide between the Wichita and the Red River east from Electra, and on some of the hills north and west of Iowa Park. It caps the bluffs on the north side of the Wichita at several points southwest of Iowa Park. It was noted on the north shelf of Beaver Creek, at a point nearly due south of Electra, and again it was found capping the highest point of land on the divide between this creek and the Wichita River, in the southwest corner of Wichita County. Everywhere this conglomerate resembles stream gravel except as to its indurated condition. It is cemented with copious calcareous material, often of a cinnamon color. Cross-bedded sand is generally interbedded with the gravel, and occasionally it contains streaks of yellow and calcareous silt. It appears that this conglomerate is one of the remnants of a long series of stream sediments which have been laid down on the Plains during a time dating back from the late Tertiary age to the late Pleistocene.

An examination of the boulders and pebbles in this conglomerate on Beaver Creek shows that different kinds of rocks are represented by percentages about as indicated in the table below, where similar percentages are also given for pebbles from the gravels in Wichita River.

Kinds of rock.	Boulders from upland conglomerate about three inches in diameter.	Pebbles from upland conglomerate about one-third inch in diameter.	Pebbles from Wichita River one-third inch in diameter.
Quartzite, very hard, in part of dark purple color	44	5	3
Quartzite schist, containing minute crystals of magnetite, and having an amethystine lustre, on a fractured surface	36	15	------
Structureless quartz	12	2	27
Chert or flint	4	9	13
Vein quartz	2	33	------
Silicified wood	2	1	------
Limestone, in part calcareous concretions	------	35	55
Sandstones	------	1	------
Granite	------	------	2

PRODUCTION AND COMPOSITION OF OIL.

The Henrietta (Petrolia) field, while of chief importance on account of its supplies of natural gas, also has a monthly production of about 10,000 barrels of a high grade oil. The maximum gas supply has never been even remotely approached by consumption, but conservative estimates place the available amount as at least two hundred million cubic feet a day. Some estimates exceed this by one-half. See Appendix II, page 283, for a brief discussion of this gas by W. B. Phillips.

The Electra field has had no commercial importance in gas production. Enough gas to run pumping engines and to fire boilers has been obtained from some wells. The maximum production of oil was about 13,000 barrels a day, in November, 1911, but this was not maintained for any long time, and the field is not now (May, 1912), producing more than 10,000 barrels a day. The oil is of a very high grade, and has steadily increased in price since the opening of the field.

Deep Sand Oil of the Henrietta Field.

As before stated, the lower of the two Deep Group sands at Henrietta has shown the larger development and the greater capacity in gas production. Single wells of a capacity of 30,000,000 cubic feet of gas a day have been drilled into this sand, and have maintained this output for months. The small amount of deep oil produced in this field has come almost entirely from this sand, and it seems not at all unlikely that more oil wells will be drilled in as the limits of the gas become more distinct. The maximum reported yield of oil from this sand was in Dunn No. 1, of the J. M. Guffey Petroleum Co., which started with 700 barrels from 1750 feet. This well did not long maintain this flow and it is now some two and a half years later, not making more than 50 barrels. Other deep wells have had initial flows of 100 barrels, but the average is probably considerably below this figure. If we were to include in an average all the deep wells in the field, those yielding no oil except in drips from the gas line as well as those now pumping, the daily yield would probably be less than 10 barrels per well.

The oil from this Deep sand is a high grade light oil excellently adapted to refinery use. The high percentage of gasoline might lead one to the belief that the accompanying gas would yield gasoline in commercial quantities on treatment. A sample of oil, taken in person by one of the authors, was analyzed in the laboratory of the Bureau. This analysis is as follows:

Analysis No. 213.—Crude petroleum from Dunn No. 1 of J. M. Guffey Petroleum Co., at Petrolia, Clay County, Texas, from a depth of 1750 feet. Sampled from pump line on March 13, 1912, by Drury Phillips.

Color	Reddish brown.
Specific gravity	0.802=44.9 B.
Viscosity	36 at 72 deg. F.
Flash point	72 deg. F.
Burning point	72 deg. F.
Heating power	19,860 B. T. U. per pound
Sulphur	Trace

Distillation at a room temperature of 72 deg. F. and barometer at 29.5 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F	35.00	colorless
2. 302 deg. to 392 deg. F	10.00	colorless
3. 392 deg. to 482 deg. F	9.00	slightly opaque
4. 482 deg. to 572 deg. F	12.50	yellowish opalescent
5. Above 572 deg. F	20.50	"orange pale."
6. Residuum, by weight	6.20	

S. H. WORRELL, Analyst.

A sample of a solid black substance, said by the pump-tender to have accumulated on the valves at the bottom of the well to such an extent as to make "steaming" necessary, was also examined. It was a natural paraffin similar to those noted in other fields* and was found to consist of bitumen with some high grade paraffin. It has been used locally to coat pipes and tanks, but is of no commercial importance.

Deep Sand Oil of the Electra Field.

The deep sands at Electra have not been so thoroughly explored as at Petrolia, and such work as has been done has shown them to be more variable. Some deep wells have been large and steady producers, while others not far removed have been dry or small pumpers. The largest well in the field is the Putnam No. 3, of the old Clayco Oil and Pipe Line Co., now Corsicana Petroleum Co. This had an initial production of 1600 barrels from 1890 feet, and nine months later was still flowing 600 barrels. Stringer No. 4, of the Producers Oil Co., one location west of Putnam No. 3, found a sand at 1895, but this was not good enough to stop in, and the well was drilled to a lower sand at 1942 feet. A little farther east of Putnam No. 3, Woodruff No. 2, of the Corsicana Petroleum Co., went several hundred feet lower and was dry, but Dale No. 1, of the 99 Pumping Co., found a small pay sand at a level to correspond to that in Putnam No. 3. Still further east Buerbaum No. 1 was dry in all these sands. North of these wells McBride-Sheldon No. 1 is a good producer at 1950 feet, while Whitehill-Burns No. 1 was dry, when down more than 2000 feet. Just south of Putnam No. 3, a group of Waggoner wells have been steady producers from these deep sands, but south of the railroad the wells have not kept up their initial production and some have never yielded oil at all in paying quantities. These are instances showing the variable nature of the deep sands in this field.

The oil is similar to that found in the deep wells of the Henrietta field, being a high grade light oil, excellently adapted to refinery use. Three samples of this oil were taken, in three different parts of the field, and from two depths. The oil from Bywaters Nos. 1 and 2, on the west of the field at a depth of 1835 feet is the same as that from Putnam No. 3 in the center at a depth of 1890 feet. Dale No. 1 was thought to be an "edge well" and the oil at a depth of 1910, corresponding to 1890 feet in Putnam No. 3, shows a heavier gravity and a smaller amount of light fractions. These analyses follow:

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*Petroleum Mining, A. Beeby Thompson, p. 299.

Analysis No. 205.—Crude petroleum from Bywaters Nos. 1 and 2, western part of the Electra field, Wichita County, Texas, from a depth of 1835 feet. Wells pumping about 40 barrels each. Sampled from pump line March 13, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.816=42 deg. B.
Viscosity	40 at 70 deg. F.
Flash point	70 deg. F.
Burning point	70 deg. F.
Heating power	17,100 B. T. U. per pound
Sulphur	Trace

Distillation at a room temperature of 70 deg. F and a barometer at 29.2 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	28.50	colorless (naphtha)
2. 302 deg. to 392 deg. F.	11.00	colorless (napthha)
3. 392 deg. to 482 deg. F.	13.00	colorless (naphtha)
4. 482 deg. to 572 deg. F.	12.00	colorless (naphtha)
5. Above 572 deg. F.	22.00	brown, heavy and turbid
6. Residuum, by weight	15.00	

Note: No. 5 distillate solidifies at 48 deg. F. with appearance of vaseline.

S. H. WORRELL, Analyst.

Analysis No. 206.—Crude petroleum from Putnam No. 3, center of the Electra field, Wichita County, Texas, from depth of 1890 feet. Flowing 600 barrels. Sampled from flowing line March 13, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.817=41.7 deg. B.
Viscosity	38 at 72 deg. F.
Flash point	72 deg. F.
Burning point	72 deg. F.
Heating power	18,170 B. T. U. per pound
Sulphur	Trace

Distillation at a room temperature of 72 deg. F. and barometer at 29.17 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	26.00	colorless
2. 302 deg. to 392 deg. F.	13.50	colorless
3. 392 deg. to 482 deg. F.	12.50	colorless
4. 482 deg. to 572 deg. F.	13.00	yellowish opalescent
5. Above 572 deg. F.		
1st portion	13.00	yellow, "extra pale"
2nd portion	9.00	yellow, "orange pale"
6. Residuum, by weight	12.00	

S. H. WORRELL, Analyst.

Analysis No. 210.—Crude petroleum from Dale No. 1, of the 99 Pumping Company, in southeastern part of Electra field, Wichita County, Texas, at a depth of 1910 feet. Well pumping about 20 barrels a day. Sampled from tanks on March 13, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.844.=36.3 deg. B.
Viscosity	38 at 70 deg. F.
Flash point	70 deg. F.
Burning point	70 deg. F.
Heating power	18,500 B. T. U. per pound
Sulphur	Trace

Distillation at a room temperature of 70 deg. F. and barometer at 29.6 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	20.00	colorless
2. 302 deg. to 392 deg. F.	15.00	colorless
3. 392 deg. to 482 deg. F.	12.00	colorless
4. 482 deg. to 572 deg. F.	11.00	yellowish opalescent
5. Above 572 deg. F.	20.00	"orange pale"
6. Residuum, by weight	14.20	

S. H. WORRELL, Analyst.

Middle Sand Oil of the Henrietta Field.

It is from the sands of this and the Shallow Group that the bulk of production in this field has come. None of these wells have at any time been large producers, few showing a greater yield than 10 barrels a day. Some have averaged 5 barrels a day for three years, though the general yield is less than this. A small amount of salt water nearly always accompanies the oil.

This oil is heavier than that from the deep sands, and contains less of the lighter distillates, as shown in the following analyses:

Analysis No. 212.—Crude petroleum from Hunt-McGregor well in center of Petrolia field, Clay County, Texas, from 720 feet. Well was pumping five barrels a day. Sampled from pump line on March 15, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.820=40.8 deg. B.
Viscosity	40 at 77 deg. F.
Flash point	77 deg. F.
Burning point	77 deg. F.
Heating power	19,850 B. T. U. per pound
Sulphur	Trace

Distillation conducted at room temperature of 77 deg. F. and barometer at 29.5 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	25.00	colorless
2. 302 deg. to 392 deg. F.	13.50	colorless
3. 392 deg. to 482 deg F.	9.50	colorless
4. 482 deg. to 572 deg. F.	13.00	yellowish opalescent
5. Above 572 deg. F.	23.00	"orange, pale"
6. Residuum, by weight	16.00	

S. H. WORRELL, Analyst.

Middle Sand Oil of the Electra Field.

By far the greatest production of the entire region has been shown by the sands of this group. None of the wells have been really big producers. In November, 1911, the average yield was 350 barrels a day from about forty wells. As more wells were drilled, however, both the total and the average decreased, till with about one hundred wells, the average was less than one hundred barrels. The lower of the two principal sands of this group is the more productive, as will be seen from the table on page 118. Flowing wells are more frequently found in the lower sand. The extremely irregular production of the sands may be seen in the group of Skinner and Allen wells a little west of the center of the proven field. Here a good sand, yielding from 100 to 300 barrels, was found in the seven wells shown at depths of from 997 to 1010 feet. A well one location north of No. 16 was dry to 1845 feet, and a well one location north of

No. 19 had only 15 barrels at 1027 feet. Such conditions are not rare in this field, where even in the center of the pool a few feet may mark the difference between a paying well and a dry hole.

The oil is of the same nature as that from the deep sand. As in the case of Dale No. 1, of the 99 Pumping Co., thought to be an "edge well" in the deep sands, so Bickley No. 1 of the Producers Oil Co. is thought to be an "edge well" in the middle sands. It shows about the same difference in composition from the other oils of its group that the Dale oil shows from its group.

Analysis No. 208.—Crude petroleum from Hamilton No. 1, of the Corsicana Petroleum Company, Electra field, Wichita County, Texas, at a depth of 974 feet. Well was pumping 100 barrels a day. Sampled from tank on March 13, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.813=42.5 deg. B.
Viscosity	37 at 72 deg. F.
Flash point	72 deg. F.
Burning point	72 deg. F.
Heating power	18,910 B. T. U. per pound
Sulphur	Trace

Distillation at a room temperature of 72 deg. F. and barometer at 29.4 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	27.00	colorless
2. 302 deg. to 392 deg. F.	12.00	colorless
3. 392 deg. to 482 deg. F.	12.50	colorless
4. 482 deg. to 572 deg. F.	11.00	colorless
5. Above 572 deg. F.	24.00	yellowish opalescent
6. Residuum, by weight	12.30	

S. H. WORRELL, Analyst.

Analysis No. 207.—Crude petroleum from McBurney No. 1, of the Producers Oil Co., Electra field, Wichita County, Texas, at a depth of 812 feet. Well flowing 215 barrels a day. Sampled from line on March 13, 1912, by Drury Phillips. Practically the same as analysis No. 208.

S. H. WORRELL, Analyst.

Analysis No. 209.—Crude petroleum from Bickley No. 1, of the Producers Oil Co., Electra field, Wichita County, Texas, at a depth of 870 feet. Well pumping 8 barrels a day. Sampled from tank on March 13, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.845=36.1 deg. B.
Viscosity	38 at 72 deg. F.
Flash point	74 deg. F.
Burning point	74 deg. F.
Heating power	18,525 B. T. U. per pound.
Sulphur	Trace

Distillation at room temperature of 74 deg. F. and barometer at 29.2 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F	20.00	colorless
2. 302 deg. to 392 deg. F	15.00	colorless
3. 392 deg. to 482 deg. F	10.00	colorless
4. 482 deg. to 572 deg. F	15.00	yellowish opalescent
5. Above 572 deg. F	18.00	"orange pale"
6. Residuum, by weight	17.70	(pitchy)

S. H. WORRELL, Analyst.

Shallow Sand Oil of the Henrietta Field.

The most reliable strata for the production of oil in this field lie along the crest of the elongated dome, in a strip approximately two miles long and a mile wide. In this area there are probably three hundred wells, most of which have at some time been producers. The two sands locally known as the 260-foot sand and the 350-foot sand, are easily the largest producers, and considerable oil has been found in a sand at about 160 feet in the northern part of this strip. The two principal sands seem of equal reliability, and the lower of greater productivity, the wells in this sand averaging possibly a barrel a day more than those in the shallower stratum. This slight difference, where a yield of five barrels a day is considered above the average, is almost negligible.

The oil from these shallow sands is heavier than that from the 720-foot sand, which in turn is heavier than the deep oil. There is even noticeable a slight difference in specific gravity and the per cent of lighter distillates in two oils, one from the 350-foot sand, and one from the 260-foot sand. The deeper oil is lighter and has larger quantities of gasoline and kerosene in the first two fractions. Complete analyses follow:

Analysis No. 214.—Crude petroleum from the Hunt McGregor wells in center of the Henrietta field, Clay County, Texas, from a depth of 350 feet. Two wells were pumping about four barrels each into same line, from which sample was taken. Sampled March 15, 1912, by Drury Phillips.

Color	Reddish brown
Specific gravity	.845=39.5 deg. B.
Viscosity	55 at 64 deg. F.
Flash point	64 deg. F.
Burning point	64 deg. F.
Heating power	20,140 B. T. U. per pound
Sulphur	Trace

Distillation at room temperature of 64 deg. F. and barometer at 29.5 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	19.00	colorless
2. 302 deg. to 392 deg F.	11.50	colorless
3. 392 deg. to 482 deg. F.	14.00	colorless
4. 482 deg. to 572 deg. F.	10.50	yellowish opalescent
5. Above 572 deg. F.	33.00	"orange pale"
6. Residuum, by weight	13.00	

S. H. WORRELL, Analyst.

Analysis No. 211.—Crude petroleum from Joyce wells toward southern edge of Henrietta oil field, Clay County, Texas, from a depth of 260 feet. Well was pumping about three barrels a day. Sampled from line on March 15, 1912, by Drury Phillips.

Color	Reddish brown.
Specific gravity	.861=32.8 deg. B.
Viscosity	64 at 66 deg. F.
Flash point	66 deg. F.
Burning point	78 deg. F.
Heating power	18,000 B. T. U. per pound
Sulphur	Trace

Distillation at room temperature of 66 deg. F and barometer at 29.6 inches.

Fractions.	Per cent.	Color.
1. Up to 302 deg. F.	18.00	colorless
2. 302 deg. to 392 deg. F.	10.00	colorless
3. 392 to 482 deg. F.	11.00	colorless
4. 482 deg. to 572 deg. F.	17.00	yellowish opalescent
5. Above 572 deg. F.	30.00	"orange pale"
6. Residuum, by weight	12.70	

S. H. WORRELL, Analyst.

Shallow Sand Oil of the Electra Field.

The single shallow producing sand that has been found with some regularity lies at about 530 feet below the surface. This seems to have a limited extent, and is found best developed west of the center of the pool. In some cases gas was reported from this sand, but not in commercial quantities. The wells are smaller than the average in the field, rarely yielding more than 50 barrels a day. This production they seem to maintain better than is the case with the production in deeper wells.

Discovery of Oil in Electra Field.

The first reported occurrence of oil in this field was in a well dug in 1900 for water. A well north of what was then Beaver Station found oil at 147 feet. South of the station another well found oil at 205 feet, supplies amounting to 20 gallons. Several barrels of oil were obtained from the first well, and a sample was sent away for analysis. This analysis is as below:

Casper, Wyo., June 21, 1900.

REPORT AND ANALYSIS OF BEAVER, TEXAS, CRUDE PETROLEUM.

Specific gravity of crude oil=.896 at 60 deg. F.
Deg. Beaumé =32 at 60 deg. F.

Fractional distillation of 1000 ccm crude. Divided into fractions of 50 ccm. each.

No.	ccm.	Spec. Grav.	Deg. Bé.
1.	50	.7230	65
2.	50	.7557	57.3
3.	50	.7680	54
4.	50	.7808	51
5.	50	.7940	47.6
6.	50	.8070	44.9
7.	50	.8156	43
8.	50	.8295	40
9.	50	.8400	37.5
10.	50	.8488	36
11.	50	.8742	31
12.	50	.8957	27

Practical refining and yields in commercial products.

Naphtha (Benzene) 65 deg. B.........	10 per cent
Kerosene 47 deg. B. 150 deg. F........	40 per cent
Light intermediate distillate 36 deg. B.	10 per cent
Heavy distillate 29 deg. B............	15 per cent
Hard elastic asphalt (residue)........	25 per cent
	100 per cent

The Kerosene and Benzene are of good quality, containing but small traces of sulphur compound. The distillates have no lubricating properties, but are suitable for gas making.

If the heavy distillates and light distillates are not distilled off and only Naphtha and Kerosene are extracted, the residue forms a liquid asphalt suitable for fluxing Trinidad or other hard rock asphalts used in the paving and roofing line.

Samples 1-2 represent sample of Naptha.

Samples 3-10 represent sample of Kerosene.

Samples 11-12 represent sample of distillates.

Very respectfully,

(Signed) DR. F. SALATHE,
Mgr. and Supt.

Summary of Production of Electra Field.

The importance of the Electra field lead to the preparation of the following table, which is self-explanatory. The yield from the 1040 foot sand proves its right to be considered the most reliable producer of the field.

TABLE SHOWING THE NUMBER OF WELLS PRODUCING FROM EACH OF THE SANDS AT ELECTRA, AND THE INITIAL PRODUCTION OF EACH, IN HUNDREDS OF BARRELS PER DAY, TO APRIL, 1912.*

From	Initial Production in Barrels Per Day.											All wells.
	0 to 100	101 to 200	201 to 300	301 to 400	401 to 500	501 to 600	601 to 700	701 to 800	801 to 900	901 to 1000	Ab've 1000	
530-foot sand..	11	1	------	------	------	------	------	------	------	------	------	12
820-foot sand..	6	3	3	------	------	------	------	------	------	------	------	12
955-foot sand..	6	3	3	4	------	------	2	1	------	------	1	20
1040-foot sand	13	7	6	1	2	3	1	------	------	1	1	35
Deep sands, below 1700 feet	8	4	2	1	1	------	------	------	------	------	1	17
Stray sands, above 1000 feet	7	5	------	------	------	------	------	1	------	------	------	13
Stray sands, below 1000 feet	7	6	4	------	------	------	------	------	------	------	------	17
All sands......	58	29	18	6	3	3	3	2	------	1	3	126

*The data are compiled from the Oil and Gas Journal.

APPENDIX I.

Notes and Acknowledgments.

The following well records are given word for word as they were copied by the authors from the various sources available. No effort has been made to edit or interpret them, and the drillers' descriptions are in every case preserved.

A few of the records are "memory logs," furnished by the drillers in some cases months or even years after the drilling of the well. This is more notably the case with one or two of the shallow wells. With the wells indicated as belonging to any of the larger operators, the records have in most cases been taken direct from official copies of drillers' logs, as reported at the time of drilling. These records vary in detail, as is to be expected, but most of them are fairly reliable indices of the formations. Elevations were obtained from level surveys by one of the larger companies operating in these fields; estimated elevations were often obtained with the assistance of aneroid or hand level.

For the bulk of these well records, we are particularly indebted to the following firms and individuals. to whom we wish to express our appreciation of favors shown:

The Lone Star Gas Company, Fort Worth, Texas; The Producers Oil Company, Houston and Wichita Falls, Texas; The Corsicana Petroleum Company, Corsicana and Electra, Texas; The Gulf Refining Company, Wichita Falls, Texas; The Clayco Oil & Pipe Line Company, Petrolia, Texas; The Red River Oil Company, Electra, Texas; The 99 Pumping Company, Beaumont, Texas; Messrs. W. E. Wrather, George Bumbaugh, A. A. Little, Sidney Webb, W. B. Chaffee, Henry Nichols, Harvey Landrum, J. E. Hardenburg, Bert Leonard, W. S. Mowris, Ed. Dismukes, J. F. O'Neal, J. B. Winfrey, J. Y. and J. W. Culbertson, and others.

Baylor County.

No. 1.—Webb No. 1, Devonian Oil Co. This well is located two and one-half mies southeast of Fuda in Baylor County. The following log is incomplete:

	——Feet——		
	From	To	Thickness
Top, red clay..........	0	25	25
Clay and gravel........	25	35	10
Red clay..............	35	120	85
Blue clay..............	120	165	45
Red clay...............	165	250	85
Blue clay..............	250	305	55
Fire clay..............	305	325	20
Red clay...............	325	375	50
Gray clay..............	375	430	55
Red clay...............	430	440	10
Gray clay..............	440	450	10
Shell	450	457	7
Clay	457	500	43
Water sand............	500	510	10
Blue clay..............	510	545	35
Sand water	545	550	5
Clay	550	555	5
Hard lime shell.........	555	560	5
Blue clay..............	560	600	40
Water sand............	600	615	15
Blue clay..............	615	630	15
Red clay..............	630	670	40
Blue clay..............	670	700	30
Red clay...............	700	790	90
Sand, water............	790	805	15
Clay	805	845	40
White shale............	845	900	55
Blue clay..............	900	920	20
White sand............	920	930	10
Red clay...............	930	945	15
Hard shell.............	945	949	4
Red clay..............	949	960	11
Sand water	960	965	5
Clay	965	970	5
Sand, water............	970	975	5
Red clay...............	975	1025	50
Blue shale.............	1025	1040	15
Sand, water............	1040	1045	5

Soft clay, colored	1045	1132	87
Sand, water	1132	1140	8
Blue clay	1140	1175	35
Sand, water	1175	1190	15
Soft clay	1190	1200	10
Solid blue shale	1200	1205	5
Blue cave	1205	1240	35
Sand, water	1240	1248	8
Gray cave	1248	1258	10
Sandy shells	1258	1262	4
Blue shale	1262	1275	13
Soft blue clay	1275	1300	25
Gray shale	1300	1355	55
Sand, water	1355	1380	25
Slate	1380	1390	10
Red clay	1390	1405	15

Wilbarger County.

No. 2.—Webb No. 1, Guffey Petroleum Co. This well is located five miles south-southwest of Electra in Wilbarger Co. Drilling had progressed to a depth of 1600 feet with no paying oil or gas sands. Examination of a mixed shale from a depth of 1500 feet showed it to consist of dark green, red and black fragments. One fragment of black shale showed a leaf impression, and some imbedded crinoid joints. Pyrite is present and Rhombopora lepidodendroides was noted.

No. 3.—Allingham No. 1. Electra Oil Field Co. The well is about one mile northeast of No. 2, and had reached a depth of 789 feet.

No. 4.—Tate No. 1, Producers Oil Co. Elevation, 1133. The well is about three miles northwest of Electra.

Samples examined: 1420-1422 feet. A greenish-gray sandstone, the grains mostly from ½ to ¼ mm. in diameter. It contains dull green imbedded particles and a calcareous cementing material.

1555-1561 feet. A gray salt sand, containing fragments of green shale, some organic lime and some red lime. The sand grains are from ½ to ¼ mm. in diameter.

1630 feet. A fine textured slightly calcareous greenish-gray and red shale. Slickenside joints and pyrites were noticed. Some few fragments of a gray sandy rock showed portions of fish scales and sponge spicules. Sulphur and oil fumes were noted when the sample was heated in a closed tube.

1655-1661 feet. Gray oil sand. It is of fine texture, a greenish-gray quartz sand carrying some green shale, and some fragments of a dirty amber-colored limestone of waxy lustre. Portions of this lime were organic.

1661-1665. Like the preceding, but coarser.

	Feet		
	From	To	Thickness
Red mud	0	50	50
Oil sand	50	55	5
Red mud	55	135	80
Blue mud	135	270	135
Red mud	270	285	15
Blue mud	285	320	35
Red mud	320	370	50
Blue mud	370	385	15
Red mud	385	500	115
Dry sand	500	510	10
Red mud	510	530	20
Blue shale	530	550	20
Red mud	550	575	25
White mud	575	625	50
Blue mud	625	675	50
Red mud	675	700	25
Blue mud	700	725	25
Gray mud	725	858	133
Red rock	858	900	42
Gray shale	900	932	32
Sand, oil	932	936	4
Gray shale	936	990	54
Lime shell	990	996	6
Blue shale	996	1025	29
Gray shale	1025	1050	25
Lime shell	1050	1056	6
Red shale	1056	1080	24
Shell	1080	1085	5
Red mud	1085	1100	15
Brown shale	1100	1140	40
Shell	1140	1144	4
Red shale	1144	1190	46
Blue shale	1190	1250	60
Red mud	1250	1300	50
Light shale	1300	1350	50
Brown shale	1350	1375	25
Blue shale	1375	1390	15
Lime shell	1390	1396	6
Light shale	1396	1435	39
Blue slate	1435	1480	45
Sand, salt water	1480	....	..

No. 5.—Waggoner No. 7. Producers Oil Co. Elevation, 1245. Drilling commenced May 6, 1911. Drilling finished Sept. 9, 1911. 198 feet of 12½-inch casing; 496 feet of 10-inch casing; 1336 feet 4

inches of 8-inch casing; 1836 feet of 6-inch casing. Pumping 30 barrels. This is the westernmost, and one of the deepest, producing wells in this field.

	Feet		
	From	To	Thickness
Red and blue mud	0	610	610
Sand, oil	610	615	5
Red and blue mud	615	790	175
Dry sand	790	800	10
Red slate	800	820	20
Water, sand	820	836	16
Red slate	836	851	15
Sand	851	881	30
Blue slate	881	886	5
Red slate	886	915	29
Blue shale	915	1005	90
Sand, oil show	1005	1008	3
Blue slate	1008	1048	40
Red slate	1048	1083	35
Red and blue with shells	1083	1145	62
Brown shale	1145	1150	5
Red and blue slate	1150	1200	50
Blue and red slate	1200	1225	25
Lime shell	1225	1230	5
Sand	1230	1279	49
Blue slate	1279	1315	36
Sand	1315	1330	15
White slate	1330	1340	10
Blue slate	1340	1355	15
White lime	1355	1380	25
Blue shells	1380	1395	15
Sand	1395	1413	18
White mud	1413	1420	7
Blue mud	1420	1480	60
Hard red mud	1480	1505	25
Blue mud	1505	1545	40
Red mud	1545	1595	50
Blue mud	1595	1610	15
Sand	1610	1627	17
Blue mud	1627	1645	18
Sand	1645	1654	9
Blue shells	1654	1704	50
Red mud	1704	1714	10
Blue shells	1714	1735	21
Red shale	1735	1740	5
White lime, sand	1740	1780	40
Blue shale	1780	1805	25

Lime shell	1805	1808	3
Dry sand	1808	1813	5
Blue shale	1813	1838	25
Oil, sand	1883	1865	27
Blue shale	1865	1880	15
Lime shell	1880	1883	3
Blue shale and shell	1883	1960	77

No. 6:—Waggoner No. 5. Producers Oil Co. Elevation, 1263. Drilling commenced June 12, 1910. Drilling finished January 5, 1911. 60 feet of 12½-inch casing; 612 feet of 10-inch drive; 830 feet of 8-inch drive; 1233 feet of 6-inch drive; 204 feet of 6-inch line; 1832 feet of 4 1-2-inch drive. Drillers: W. H. Ellinger and Clyde Rogers. Pumping 45 barrels a day. Sand from 1818 to 1838 feet had good show of gas in top, and last 3 feet slight show of oil. Standing over, 48 hours showed bailer full of oil. Sand from 1840 to 1852 showed small amount of gas and oil in last 7 feet. Working barrel is 35 feet off bottom with an 8-foot gas anchor. Well was contracted to depth of 1152 feet, drilled to 1832 with rotary by P. O. Co., and finished with cable tools.

		——Feet——	
	From	To	Thickness
Red and blue sand	0	395	395
Sand rock	395	410	15
Red and blue sand	410	805	395
Sand (some water)	805	825	20
Red clay	825	835	10
Sand (salt water)	835	860	25
Red and blue mud	860	905	45
Sand rock (good show of oil)	905	910	5
Red and blue mud	910	925	15
Sand rock	925	927	2
Red and blue shale	927	1152	225
Red shale	1152	1175	23
Blue shale	1175	1180	5
Red shale	1180	1229	49
Lime shell	1229	1233	4
Water, sand	1233	1282	49
Blue shale	1282	1364	82
Broken sand	1364	1389	25
Water, sand	1389	1404	15
Broken sand	1404	1430	24
Red shale	1430	1450	20
Blue shale	1450	1462	12
Red shale	1462	1485	23

Blue shale	1485	1493	8
Red shale	1493	1537	44
Blue shale	1537	1545	8
Salt water, sand	1545	1575	30
Red mud	1575	1600	25
Lime rock	1600	1610	10
Red mud	1610	1660	50
Lime rock	1660	1670	10
Red mud	1670	1700	30
Lime rock	1700	1705	5
Blue mud	1705	1720	15
Lime rock	1720	1725	5
Sand rock	1725	1728	3
Salt water, sand	1728	1760	32
Blue shale	1760	1791	31
Sand rock	1791	1792	1
Blue shale	1792	1796	4
Lime rock	1796	1799	3
Blue shale	1799	1818	19
Sand, brown	1818	1838	20
Blue shale	1838	1840	2
Gray, soft sand	1840	1852	12

No. 7.—Rogers No. 1. Producers Oil Co. Elevation, 1245. Depth, about 2600 feet and drilling. In this well the greatest thickness of lime encountered in the entire district was met at 2450 feet, extending for a distance of about 200 feet with small breaks of shale and little sand. A showing of oil was reported at 1865, at 2146, and at 2370 feet.

Samples examined:

1825-1840. A black shale with fragments of white organic limestone, giving strong sulphur fumes when heated in a closed tube. Coal and pyrite are present. Bryozoa, Cythere (?) (smooth) and Fusulina were noted.

2370. "Skim of greenish oil." A finely comminuted grayish white calcareous limestone, with flat and oval amber-colored discs 1-2 mm. on longer axis. A flat coiled Ammodiscus. Fragments showing microscopic pits in rectangularly arranged rows were found and other organic fragments.

2380-2395. A yellow limestone containing fragments of cup coral, Fusulina and spines of brachiopods. Some fragments of gray shale.

2395-2400. A white limestone containing fragments of unrecognizable fossils and round and oval bodies less than 1-4 mm. in diameter, some of which are olive colored.

2475. A white limestone containing much pure calcite, and fragments of obscure organic remains. Double crystals of calcite were noted in numbers.

2500-2535. Large sample from dump. Dark red, gray and black shale and some limestone. A bituminous odor was distinct on heating in a closed tube. The limestone is white and yellow. Chaetetes (?), several specimens of flat coiled Ammodiscus, some small ostracods and one bryozoan were noted.

2537. A gray limestone with much pyrite, some clear calcite and shell fragments. Some exceedingly fine sandstone or sandy gray shale also present.

About 2550. From under a thick lime. A dark fire clay, containing pyrite and coal fragments showing vegetable tissue, with many particles of a finely granular fire clay in which are many microscopic specks of carbonaceous material. Fusulina is frequent and a small ribbed shell fragment was noted. Ammonia fumes evident on heating.

About 2560. Pure white limestone, structureless under hand glass but largely crystalline under 50x magnification, with crystals quite uniform in size. It effervesces promptly. A few minute calcareous cylindric spicules were noted.

2575. A pure white fine grained limestone, showing many lignilitic joints, considerable calcite and a few fragments with indistinct organic structure. The sample darkens on heating in a closed tube.
Figure 8.

The partial log follows:

	Feet		
	From	To	Thickness
Red mud	0	100	100
Blue mud	100	125	25
Red mud	125	160	35
Oil and water, sand	160	170	10
Red mud	170	270	100
Blue mud	270	290	20
Red mud	290	425	135
Blue and red mud	425	460	35
Dry sand	460	480	20
Blue and red mud	480	500	20
Blue shale	500	525	25
Red mud	525	535	10
Blue mud	535	600	65
Red mud	600	615	15
Blue mud and shells	615	655	40
Water, sand	655	690	35
Red mud	690	715	25
Blue mud	715	765	50
White mud	765	775	10
Red mud	775	825	50
Water, sand	825	840	15

Blue mud	840	875	35
Red mud	875	920	45
Blue mud	920	924	4
Oil, sand	924	930	6
Red mud	930	950	20
Blue mud	950	960	10
Red mud	960	975	15
Blue mud	975	1015	40
Red mud	1015	1090	75
Blue mud	1090	1105	15
Oil and water, sand	1105	1120	15
Sand and break	1120	1135	15
Water, sand	1135	1155	20
Blue and red mud	1155	1220	65
Blue mud	1220	1234	14
Red mud	1234	1240	6
Blue mud	1240	1245	5
Water, sand	1245	1255	10
Red and blue mud	1255	1305	50
Blue mud shells	1305	1390	85
Water, sand	1390	1430	40
Red mud	1430	1530	100
Hard sand	1530	1540	10
Red and blue mud	1540	1555	15
Dry hard sand	1555	1565	10
Red and blue mud	1565	1575	10
Light blue mud	1575	1585	10
Red mud	1585	1600	15
Blue mud shells	1600	1700	100
Sand shells	1700	1705	5
Blue mud	1705	1720	15
Lime shell	1720	1725	5
Blue shale	1725	1740	15
Red mud	1740	1752	12
Sand, broken	1752	1790	38
Black shale	1790	1820	30
Blue shale	1820	1825	5
Shale and shells	1825	1840	15
Red and blue mud	1840	1845	5
Dry sand	1845	1850	5
Black slate shells	1850	1865	15
Oil sand	1865	1870	5
Black slate shells	1870	1885	15
Black shale	1885	1900	15
Hard lime	1900	1908	8
Brown shale	1908	1912	4
Blue shale streaks sand	1912	1938	26

Blue slate	1938	1970	32
Lime	1970	1983	13
Red slate	1983	1985	2
Blue slate	1985	2010	25
Red slate	2010	2028	18
Blue slate	2028	2072	44
Blue slate shells	2072	2080	8
Lime shells	2080	2143	63
Blue slate and shells	2143	2146	3
Sand, oil show	2146	2156	10
Blue slate	2156	2166	10
Lime shell	2166	2181	15
Blue slate	2181	2184	3
Sand shells	2184	2202	18
Broken sand	2202	2206	4
Hard lime	2206	2215	9
Blue slate shells	2215	2223	8
Red slate	2223	2228	5
Blue slate shells	2228	2278	50
Water, sand	2278	2350	72
Blue shale shells	2350	2355	5
Lime shell	2355	2370	15
Sand, oil show	2370	2380	10
Water, sand	2380	2395	15
Gray sand	2395	2450	55
Lime	2450	....	..

No. 8.—Waggoner No. 12, Producers Oil Co.

Clay	0	24	24
Sand and gravel	24	54	30
Shale	54	354	300
Rock	354	357	3
Shale and shells	357	522	165
Hard sand rock	522	544	22
Shale	544	559	15
Rock	559	575	16
Hard shale	575	615	40
Rock	615	633	18
Shale	633	653	20
Rock	653	656	3
Hard shale	656	671	15
Rock	671	673	2
Hard shale	673	689	16
Hard sand	689	703	14
Shale and shells	703	766	63
Hard sand, gas	766	782	16
Hard shale	782	802	20

Hard rock	802	806	4
Hard shale	806	892	86
Hard sand	892	907	15
Shale	907	927	20
Hard sand	927	943	16
Shale	943	960	17
Rock	960	967	7
Hard shale	967	993	26
Sand rock	993	1001	8
Hard shale	1001	1032	31
Hard sand	1032	1036	4
Shale	1036	1040	4
Rock	1040	1043	3
Shale	1043	1055	12
Red shale	1055	1083	28
Hard sand, oil	1083	1113	30
Red shale	1113	1176	63
Lime and sand	1176	1231	55
Blue shale	1231	1281	50
Red shale	1281	1310	29
Red mud and rocks	1310	1320	10
Gumbo	1320	1330	10
Hard shale	1330	1373	43
Lime rock	1373	1377	4
Shale and shells	1377	1403	26
Lime rock	1403	1407	4
Gumbo	1407	1455	48
Blue shale	1455	1470	15
Gyp	1470	1482	12
Hard shale and gravel	1482	1500	18
Hard sand	1500	1510	10
Gyp	1510	1520	10
Sand rock	1520	1528	8
Blue shale	1528	1552	24
Hard lime	1552	1555	3
Red mud	1555	1565	10
Hard sand rock	1565	1569	4
Blue shale	1569	1590	21
Gumbo	1590	1600	10
Blue shale and boulders	1600	1661	61
Red mud	1661	1671	10
Hard rock	1671	1679	8
Gumbo	1679	1695	16
Lime rock	1695	1707	12
Blue shale	1707	1717	10
Hard sand rock	1717	1724	7
Gumbo	1724	1738	14

Blue shale	1738	1764	26
Lime rock	1764	1767	3
Blue shale	1767	1782	15
Lime rock	1782	1784	2
White mud	1784	1786	2
Oil sand, gas	1786	1790	4
Blue shale	1790	1806	16
Lime rock	1806	1808	2
Oil, sand	1808	1814	6
Blue shale	1814	1818	4
Oil, sand	1818	1828	10
Blue shale	1828	1841	13
Lime rock	1841	1844	3
Blue shale	1844	1855	11
Hard lime rock	1855	1869	14

Record not complete. The operators were bailing in this well on March 2, 1912. Said to have had good showing.

No. 9.—Waggoner No. 4. Producers Oil Co. Elevation, 1256. Depth, 2178. Drilling commenced April 15, 1910. Drilling finished August 19, 1910. This is a dry hole in what would seem to be producing territory. A little southwest, No. 6 is a producing well, and north and east Nos. 13 and 14 are producers.

	Feet		
	From	To	Thickness
Red shale	0	200	200
Red sand	200	220	20
Blue mud	220	242	22
Blue shale	242	437	195
White and blue limestone	437	452	15
Blue mud	452	460	8
Black shale	460	500	40
Blue limestone	500	502	2
Blue shale	502	524	22
Red mud	524	564	40
White crystallized limestone	564	580	16
Blue mud	580	590	10
Limestone	590	605	15
Red mud	605	613	8
Hard limestone	613	675	62
Salt water, sand	675	679	4
Hard limestone	679	690	11
Blue shale	690	735	45
Red shale	735	767	32

Blue shale	767	812	45
Red shale	812	842	30
Hard limestone	842	902	60
Red shale	902	920	18
Soft black shale	920	935	15
Salt water, sand	935	944	9
Lime shell	944	949	5
Red shale	949	965	16
Blue shell	965	1007	42
Hard limestone	1007	1013	6
Soft blue shale	1013	1088	75
Red mud	1088	1108	20
Hard sand	1108	1112	4
Soft sand, show of oil	1112	1114	2
Soft blue shale	1114	1214	100
Limestone	1214	1220	6
Hard blue shale	1220	1240	20
Red shale	1240	1305	65
Hard lime shell	1305	1310	5
Soft red shale	1310	1364	54
Hard blue shale	1364	1389	25
Hard limestone	1389	1397	8
Blue shale	1397	1407	10
Blue and red shale	1407	1442	35
Lime shell	1442	1450	8
Black shale	1450	1475	25
Blue shale	1475	1481	6
Black shale	1481	1501	20
Black gumbo	1501	1516	15
Blue gumbo	1516	1550	34
Hard blue limestone	1550	1559	9
Hard black shale	1559	1574	15
Blue shale	1574	1600	26
Blue mud	1600	1608	8
Blue and red shale	1608	1630	22
Hard blue limestone	1630	1633	3
Blue shale	1633	1658	25
Blue mud	1658	1670	12
Red and blue shale	1670	1700	30
Red shale	1700	1714	14
White lime shell	1714	1715	1
Black gumbo	1715	1725	10
Blue shale	1725	1743	18
White and blue limestone	1743	1749	6
Black gumbo	1749	1759	10
Blue shale	1759	1814	55

Blue and white lime....	1814	1817	3
Red shale.............	1817	1828	11
Hard black shale......	1828	1848	20
Blue lime shell........	1848	1864	16
Blue shale............	1864	1875	11
Hard blue lime shell...	1875	1891	16
Blue shale............	1891	1901	10
Hard white lime.......	1901	1903	2
Hard blue shale......	1903	1915	12
Brown and white crystallized limestone...	1915	1920	5
Hard blue shale........	1920	1928	8
Black gumbo..........	1928	1940	12
Hard blue lime shell..	1940	1942	2
Black gumbo..........	1942	1964	22
Hard gray limestone...	1964	1973	9
Hard black shale......	1973	1984	11
Blue shale............	1984	2061	77
Hard crystallized limestone	2061	2079	18
Salt water, sand......	2079	2081	2
Blue shale, sticky.....	2081	2097	16
Hard lime rock........	2097	2102	5
Red shale.............	2102	2131	29
Sand and streaks of lime	2131	2133	2
Lime shell and salt water, sand.........	2133	2146	13
Red and blue mud.....	2146	2151	5
Gray lime shell........	2151	2160	9
'Limestone and streaks of sand, no water....	2160	2166	6
Blue and red shale and some gravel.........	2166	2173	7
Hard blue slate.......	2173	2176	3
Limestone	2176	2178	2

No. 10.—Waggoner No. 1. Producers Oil Co. Elevation, 1251. 491 feet of 13-inch casing; 761 feet of 10-inch drive pipe; 1116 feet of 8-inch drive pipe; 1823 feet of 6-inch drive pipe. Drilled by cable. Drilling begun August 8, 1909.

	——Feet——		
	From	To	Thickness
Red clay..............	0	8	8
Sand rock............	8	15	7
Red clay..............	15	70	55

Blue clay	70	100	30
Red clay	100	145	45
Blue clay	145	205	60
Red clay	205	260	55
Blue clay	260	300	40
Red clay	300	335	35
Blue clay	335	390	55
Red clay	390	420	30
Blue clay	420	465	45
Red clay	465	485	20
Blue shale	485	495	10
Blue shale	495	555	60
Hard blue shale	555	590	35
Sand, show of oil	590	600	10
Blue shale	600	620	20
Red shale	620	660	40
Blue shale	660	735	75
Sand, rock, salt water	735	755	20
Blue shale	755	826	71
Red clay	826	846	20
Hard sand, show gas	846	866	20
Blue shale	866	880	14
Red shale	880	900	20
Hard rock	900	916	16
Blue shale	916	956	40
Red shale	956	976	20
Hard sand rock	976	981	5
Blue shale	981	1005	24
Blue shale	1005	1030	25
Hard rock	1030	1040	10
Blue shale	1040	1075	35
Red shale	1075	1095	20
Red shale	1095	1101	6
Soft red shale	1101	1115	14
Oil, sand (eight barrels per day)	1115	1123	8
Blue shale	1123	1195	72
Sand	1195	1201	6
Red slate	1201	1221	20
Blue slate	1221	1226	5
Red slate	1226	1241	15
Blue slate	1241	1261	20
Water, sand, salty	1261	1296	35
Blue slate	1296	1311	15
Lime shell	1311	1316	5
Blue slate	1316	1326	10
Red slate	1326	1339	13

Blue slate	1339	1344	5
Hard sand shell	1344	1351	7
Blue shale	1351	1375	24
Broken sand	1375	1395	20
Salt water, sand	1395	1428	33
Red slate	1428	1490	62
Blue slate	1490	1559	69
Sand shell	1559	1565	6
Blue slate	1565	1625	60
Red slate	1625	1640	15
Shells and blue slate	1640	1700	60
Blue slate	1700	1705	5
Red slate	1705	1715	10
Lime shell	1715	1720	5
Red slate	1720	1735	15
Blue slate	1735	1775	40
Red slate	1775	1795	20
Blue slate	1795	1812	17
Lime shell	1812	1816	4
Blue slate	1816	1823	7
Sand	1823	1828	5
Broken sand	1828	1848	20
Blue shale	1848	1863	15
Blue shale and lime shells	1863	1950	87
Red shale	1950	1965	15

Abandoned.

No. 11.—Waggoner No. 2. Producers Oil Co. Elevation, 1258. Depth, 1853 feet. 661 feet of 10-inch pipe; 830 feet of 8-inch drive pipe; 1030 feet of 6-inch drive pipe; 1826 feet of 4-inch drive pipe.

		Feet	
	From	To	Thickness
Red clay	0	10	10
Sand rock	10	15	5
Red and blue clay	15	165	150
Red rock	165	170	5
Red and blue clay	170	480	310
Sand (show of oil)	480	490	10
Red and blue clay	490	605	115
Sand (salt water and show of oil)	605	630	25
Red and blue clay	630	730	100
Missing	730	790	60
Sand	790	805	15
Red and blue mud	805	825	20

Sand	825	840	15
Red rock	840	950	110
Gray lime	950	958	8
Blue shale, break	958	963	5
Sand, salt water	963	978	15
Red mud	978	980	2
Light blue shale	980	1035	55
Hard lime shell (show of oil)	1035	1037	2
Lime shell break	1037	1040	3
Hard rock	1040	1093	53
Dark blue shale	1093	1107	14
Sand (show of oil)	1107	1111	4
Dark blue shale	1111	1119	8
Gray sand (small show of oil)	1119	1143	24
Sand, occasional break, salt water, little oil	1143	1275	132
Black shale	1275	1340	65
Soft blue and red mud	1340	1380	40
Gumbo	1380	1390	10
Hard blue lime	1390	1392	2
Shale and gumbo	1392	1450	58
Hard salt water, sand	1450	1466	16
Gumbo and shale	1466	1498	32
Hard lime shell	1498	1500	2
Blue and red shale	1500	1540	40
Crystallized lime rock	1540	1544	4
Gumbo	1544	1565	21
Soft blue shale	1565	1575	10
Missing	1575	1590	15
Gumbo	1590	1604	14
Hard blue shale	1604	1616	12
Hard lime shell	1616	1618	2
Blue and red shale	1618	1667	49
Hard gumbo	1667	1685	18
Hard blue shale	1685	1705	20
Red shale	1705	1726	21
Gray lime shell	1726	1738	12
Hard black shale	1738	1786	48
Hard lime shell	1786	1789	3
Blue shale	1789	1800	11
Hard black shale	1800	1823	23
Light blue shale	1823	1826	3
Hard lime shell	1826	1827	1
Blue shale, break	1827	1829	2
Sand	1829	1846	17

Blue shale, break.....	1846	1847	1
Sand (lower part contained most of oil)...	1847	1851	4
Blue shale............	1851	1853	2

Wichita County.

No. 12.—Bywaters No. 2. Producers Oil Co. Elevation, 1247. Depth, 1831 feet. Drilling commenced March 22, 1911. Drilling finished May 5, 1911. 22 feet of 10-inch casing; 1792 feet of 6-inch line pipe. Initial production, 50 barrels a day.

		——Feet——	
	From	To	Thickness
Red clay..............	0	65	65
Blue shale............	65	91	26
White gumbo.........	91	104	13
Red mud..............	104	163	59
White shale...........	163	181	18
Sand rock............	181	192	11
Blue shale............	192	280	88
Lime rock............	280	282	2
Red shale............	282	340	58
Lime rock............	340	341	1
Blue gumbo...........	341	362	21
Red mud..............	363	428	66
Lime rock............	428	431	3
Red and blue shale.....	431	486	55
Sand rock............	486	488	2
Red shale.............	488	509	21
Lime rock............	509	514	5
Red shale............	514	528	14
Lime rock............	528	530	2
White shale..........	530	556	26
Sand rock............	556	562	6
White soapy rock......	562	573	11
Red and blue shale....	573	582	9
White rock............	582	586	4
Red mud.............	586	604	18
Hard red rock........	604	611	7
Lime rock............	611	623	12
Blue shale............	623	643	20
Red rock.............	643	661	18
Hard lime rock.......	661	662	1
Blue shale............	662	670	8
Rock	670	672	2
Soft blue shale........	672	682	10
Hard shale...........	682	700	18
Shale and gumbo......	700	736	36

Lime rock	736	747	11
Mixed shale	747	803	56
Lime rock	803	804	1
Hard blue shale	804	828	24
Lime rock	828	860	32
Blue shale	860	877	17
Hard lime rock	877	880	3
Lime rock	880	886	6
Blue shale	886	930	44
Sand (show of oil and gas)	930	937	7
Lime rock	937	940	3
Blue shale	940	948	8
Red rock	948	852	4
Gumbo	952	960	8
Blue shale	960	969	9
Hard rock	969	1000	31
Red and blue shale	1000	1022	22
Hard rock	1022	1025	3
Red mud	1025	1042	17
Blue shale	1042	1053	11
Sand rock	1053	1055	2
Blue shale	1055	1075	20
Lime rock	1075	1077	2
Shale and shells	1077	1120	43
Lime rock	1120	1122	2
Sand rock	1122	1139	17
Blue shale	1139	1145	6
Red mud	1145	1176	31
Hard lime and shell	1176	1187	11
Sand, show of oil	1187	1196	9
Hard lime rock	1196	1216	20
White shale	1216	1230	14
Lime rock	1230	1240	10
Red and blue shale	1240	1260	20
Blue shale and shell	1260	1285	25
Lime rock	1285	1294	9
Blue shale	1294	1300	6
Lime rock	1300	1309	9
Hard blue shale	1309	1325	16
Soft rock	1325	1330	5
Blue shale	1330	1337	7
Lime rock	1337	1345	8
Sand	1345	1350	5
Blue shale	1350	1374	24
Sand rock	1374	1390	16
Blue shale	1390	1400	10

Lime rock	1400	1420	20
Blue shale	1420	1428	8
Lime rock	1428	1434	6
Red shale	1434	1449	15
Blue shale and shells	1449	1489	40
Sand rock	1489	1495	6
Blue shale	1495	1512	17
Sand rock	1512	1528	16
Blue shale	1528	1552	24
Sand rock	1552	1558	6
Blue shale and shells	1558	1597	39
Red mud	1597	1607	10
Hard lime	1607	1615	8
Red mud	1615	1690	75
Rock	1690	1696	6
Gyp rock	1696	1700	4
Blue shale	1700	1756	56
Lime rock	1756	1760	4
Blue shale	1760	1779	19
Lime rock	1779	1783	4
Blue shale	1783	1790	7
Hard lime	1790	1797	7
Oil, sand	1797	1808	11
Blue shale	1808	1814	6
Oil sand	1814	1816	2
Hard dark shale	1816	1830	14
Hard lime	1830	1831	1

No. 13. Bywaters No. 1. Producers Oil Co. Elevation, 1245. Depth, 1842. Drilling commenced April 18, 1910. Drilling finished August 9, 1910. 36 feet of 12 1-2-inch casing; 587 feet of 10-inch drive pipe; 833 feet of 8-inch drive pipe; 1810 feet of 6-inch drive pipe.

	Feet		
	From	To	Thickness
Red mud	0	36	36
Lime shell	36	38	2
Blue mud	38	78	40
Red mud	78	93	15
Blue shale	93	123	30
Lime shell	123	125	2
Sand, little water	125	155	30
Red mud	155	175	20
Blue shale	175	225	50
Red mud	225	265	40
Blue shale	265	355	90
Black mud	355	370	15

Red mud	370	425	55
Blue shale	425	575	150
Red mud	575	610	35
Blue shale	610	620	10
Red mud	620	650	30
Blue shale	650	670	20
Red mud	670	710	40
Blue mud	710	740	30
Lime shell	740	750	10
Blue shale	750	770	20
Salt water, sand	770	778	8
Red mud	778	820	42
Water, sand	820	828	8
Blue shale	828	863	35
Red mud	863	903	40
Blue shale	903	908	5
Red mud	908	930	22
Oil sand (80 ft. fluid after 12 hours)	930	938	8
Black shale	938	993	55
Lime shell	993	997	4
Blue shale	997	1015	18
Lime shell	1015	1018	3
Blue shale	1018	1053	35
Lime shale	1053	1059	6
Red mud	1059	1078	19
Lime shell	1078	1081	3
Red mud	1081	1096	15
Brown shale	1096	1101	5
Dry sand, bottom showed a little water	1101	1141	40
Lime shell	1141	1144	3
Red shale	1144	1184	40
Blue shale	1184	1244	60
Red mud	1244	1294	50
Blue shale	1294	1337	43
Water, sand	1337	1345	8
Red shale	1345	1363	18
Sand, show of oil	1363	1375	12
Brown shale	1375	1400	25
Blue shale	1400	1420	20
Red shale	1420	1450	30
Blue shale	1450	1480	30
Brown shale	1480	1495	15
Red shale	1495	1525	30
Blue shale	1525	1575	50
Red shale	1575	1605	30

Red slate	1605	1653	48
Red shale	1653	1693	40
Lime shell	1693	1702	9
Red shale	1702	1705	3
Crystallized limestone	1705	1710	5
Red shale	1710	1715	5
Blue shale	1715	1752	37
Red shale	1752	1809	57
Black shale	1809	1813	4
Gray sand (small amount of gas)	1813	1815	2
Oil sand (lower 9 ft. contained most oil)	1815	1827	12
Streaks of sand and brown shale	1827	1838	11
Dark slate or hard shale	1838	1842	4

No. 14.—Waggoner No. 6. Producers Oil Co. Elevation, 1246. Depth, 1839. Drilling commenced August 29, 1910. Drilling finished December 13, 1910. 40 feet of 10-inch pipe; 1800 feet of 6-inch pipe; 1821 feet of 4 1-2-inch pipe.

		——Feet——	
	From	To	Thickness
Clay	0	12	12
Water, sand	12	32	20
Yellow clay	32	42	10
Lime shell	42	43	1
Blue shale	43	75	32
Hard limestone	75	77	2
Red and blue shale	77	167	90
Soft, blue shale	167	187	20
Hard limestone	187	191	4
Soft, blue shale	191	234	43
Gray, shelly limestone	234	236	2
Blue shale	236	300	64
Gray lime shell	300	302	2
Red shale	302	384	82
Gray limestone	384	400	16
Red mud	400	403	3
Red shale	403	465	62
Blue lime rock	465	468	3
Hard blue shale	468	486	18
Red shale	486	534	48
Blue shale	534	546	12
Lime shell	546	559	13
Red shale	559	613	54

Hard blue shale	613	627	14
Shelly limestone	627	639	12
Red shale	639	652	13
Blue lime	652	661	9
Blue shale	661	680	19
Red shale	680	747	67
Lime shell	747	753	6
Blue shale	753	808	55
Water, sand	808	826	18
Red and blue shale	826	920	94
Gray water sand	920	942	22
Black gumbo	942	973	31
Limestone	973	975	2
Blue shale	975	995	20
Soft, shelly lime	995	1000	5
Blue shale	1000	1003	3
Lime rock	1003	1005	2
Gumbo	1005	1008	3
Hard lime	1008	1010	2
Gumbo	1010	1090	80
Water, sand	1090	1105	15
Blue shale	1105	1115	10
Lime shell	1115	1117	2
Red and blue shale	1117	1157	40
Water, sand	1157	1161	4
Blue shale	1161	1202	41
Water, sand	1202	1212	10
Gyp rock	1212	1224	12
Hard sand	1224	1250	26
Lime shell	1250	1256	6
Light blue shale	1256	1310	54
Hard blue shale	1310	1318	8
Hard red shale	1318	1338	20
Hard white sand	1338	1359	21
Soft blue shale	1359	1403	44
Hard lime shells	1403	1412	9
Blue shale with streaks of lime	1412	1441	29
Blue shale	1441	1503	62
Blue shale, soft	1503	1528	25
Red and blue shale	1528	1578	50
Hard limestone	1578	1585	7
Hard blue shale	1585	1600	15
Red shale	1600	1605	5
Soft red cave	1605	1612	7
Hard lime	1612	1615	3
Blue shale	1615	1620	5

Red shale	1620	1630	10
Hard blue shale	1630	1634	4
Soft blue shale	1634	1683	49
Hard shale	1683	1704	21
Blue shale	1704	1714	10
Hard lime	1714	1717	3
Blue shale	1717	1763	46
Hard lime	1763	1764	1
Shale and gumbo	1764	1800	36
Hard lime	1800	1810	10
Sand	1810	1814	4
Sand and blue shale	1814	1818	4
Sand and broken shale (show of oil)	1818	1826	8
Sand and blue shale	1826	1837	11
Blue shale	1837	1839	2

No. 15.—Waggoner No. 3. Producers Oil Co. Elevation, 1240. Depth, 1084. Drilling commenced January 24, 1910. Drilling finished March 28, 1910. 66 feet of 12 1-2-inch casing; 632 feet of 10-inch drive pipe; 608 feet of 8-inch drive pipe; 1065 feet of 6-inch drive pipe; 15 feet of 4 1-2-inch perforated.

	Feet		
Red clay	0	10	10
Red mud	10	66	56
Red and blue mixed	66	632	566
Red mud	632	675	43
Blue shale	675	740	65
Lime shell	740	742	2
Missing	742	790	48
Water sand	790	802	12
Blue shale	802	835	33
Hard lime shell	835	837	2
Red rock	837	950	113
Blue shale	950	995	45
Gray sand	995	1003	8
Blue shale	1003	1020	17
Red mud	1020	1050	30
Blue shale, hard	1050	1074	24
Oil sand, soft	1074	1084	10

No. 16.—Allen No. 3. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1204. Depth, 1043. Drilling commenced January 19, 1912. Drilling finished February 6, 1912. Water sand 814 to 844. Oil sand 1027 to 1043.

No. 17.—Allen No. 2. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1199. Depth, 1023. Drilling commenced December 4, 1911. Drilling finished December 23, 1911. Oil sand 1003 to 1013. Drilled to 1023 and plugged back to 1016.

No. 18.—Allen No. 1.—Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1200. Depth, 1057. Drilling commenced October 10, 1911. Drilling finished November 7, 1911. Oil sand 270. Oil sand 996 to 1015. Drilled to 1057 and plugged back to 1015.

No. 19.—Skinner No. 4. Producers Oil Co. Elevation, 1195. Depth, 1017. Drilling commenced February 17, 1912. Drilling finished March 9, 1912. 400 feet of 12 1-2-inch casing; 800 feet of 10-inch casing; 907 feet of 8-inch casing; 1004 feet of 6-inch casing. Well came in flowing 250 barrels from 1004 feet, while just across the line, one location west, Allen No. 4 (not on map) went to 1080 with no sand, and when found at that depth it was dry and broken.

	Feet		
	From	To	Thickness
Clay	0	3	3
Red rock	3	43	40
Blue slate	43	73	30
Red rock	73	130	57
Blue slate	130	210	80
Red rock	210	410	200
Blue slate	410	430	20
Red rock	430	460	30
Blue slate	460	480	20
Red rock	480	495	15
Blue slate	495	600	105
Sand, barren	600	615	15
Blue slate	615	665	50
Red rock	665	695	30
Sand	695	710	15
Red rock	710	730	20
Sand	730	750	20
Blue slate	750	780	30
Red rock	780	800	20
Sand, oil show	800	820	20
Red rock	820	907	87
Blue slate	907	950	43
Red rock	950	998	48
White slate	998	1004	6
Oil sand	1004	1016	12
Water, sand	1016	1017	1

No. 20.—Skinner No. 3. Producers Oil Co. Elevation, 1200. Depth, 1036. Drilling commenced January 28, 1912. Drilling fin-

ished February 14, 1912. 405 feet of 12 1-2-inch casing; 900 feet of 10-inch casing; 1015 feet of 8-inch casing. Pumping 135 barrels.

	Feet		
	From	To	Thickness
Red shale	0	22	22
Sand, water	22	26	4
Red and white shale	26	245	219
Sandy lime	245	260	15
White shale	260	348	88
Dark shale	348	405	57
Red and white shale	405	845	440
Shale	845	900	55
White shale	900	940	40
Pink slate	940	1008	68
Sand	1008	1025	17
Red shale	1025	1036	11

No. 21.—Skinner No. 2. Producers Oil Co. Elevation, 1196. Depth, 1047. Drilling commenced January 18, 1912. Drilling finished February 8, 1912. 442 feet of 12 1-2-inch casing; 845 feet of 10-inch casing; 997 feet of 8-inch casing. Pumping 75 barrels.

	Feet		
	From	To	Thickness
Red clay	0	40	40
Lime shell	40	45	5
Red rock	45	120	75
Sand, oil	120	125	5
Red rock	125	235	110
Shale	235	255	20
Red rock	255	345	90
Shell, gas	345	350	5
Red rock	350	390	40
Blue shale	390	410	20
Red rock	410	490	80
Blue shale	490	520	30
Red rock	520	540	20
Light shale	540	560	20
Oil, sand	560	580	20
Red rock	580	630	50
Blue shale	630	640	10
Red rock	640	670	30
Light shale	670	690	20
Oil, sand	690	705	15
Red rock	705	765	60
Light shale	765	775	10

Sand, barren	775	795	20
Red rock	795	825	30
Shale	825	845	20
Red rock	845	855	10
Light shale	855	903	48
Lime shell	903	910	7
Red rock	910	987	77
Sandy shale	987	997	10
Oil, sand	997	1009	12
Red mud	1009	1047	33

Oil sand from 690 to 705 good for 30 barrels.

No. 22.—Skinner No. 1. Producers Oil Co. Elevation, 1204. Depth, 1030. Drilling commenced December 8, 1911. Drilling finished January 17, 1912. 20 feet of 16-inch casing; 405 feet of 12 1-2-inch casing; 741 feet of 10-inch casing; 990 feet of 8-inch casing. Pumping 100 barrels.

	Feet		
	From	To	Thickness
Red and white slate	0	340	340
Sand	340	352	12
Slate	352	400	48
Sand, water	400	406	6
Shale	406	695	289
Sand, show oil, gas, water	695	710	15
Shale	710	990	280
Hard shell	990	995	5
Broken shell, slate	995	1000	5
Sand, oil	1000	1021	21
Shale	1021	1030	9

No. 23.—Stringer No. 15. Producers Oil Co. Elevation, 1193. Depth, 1096. Drilling commenced Jan. 18, 1912. Drilling finished Feb. 10, 1912. Flowing. Plates VIII, A, and X, B.

	Feet		
	From	To	Thickness
Soil	0	2	2
Blue clay	2	60	58
Sand	60	62	2
Red rock	62	205	143
Sand, oil	205	280	75
Red rock	280	290	10
Blue clay	290	318	28
Sand, gas	318	350	32
Lime	350	351	1
Blue clay	351	353	2

Sand	353	361	8
Lime	361	376	15
Sand	376	384	8
Blue clay	384	430	46
Lime	430	435	5
Blue clay	435	450	15
Red rock	450	490	40
Lime	490	520	30
Blue clay	520	525	5
Oil sand	525	545	20
Blue clay	545	620	75
Lime	620	622	2
Blue clay	622	650	28
Red rock	650	682	32
Lime	682	687	5
Red rock	687	720	33
Blue clay	720	765	45
Sand	765	780	15
Blue clay	780	790	10
Red rock	790	805	15
Oil sand	805	815	10
Red rock	815	825	10
Blue clay	825	845	20
Red rock	845	905	60
Blue clay	905	965	60
Oil sand	965	978	13
Blue clay	978	993	15
Lime shell	993	995	2
Red rock	995	1018	23
Lime	1018	1027	9
Sand	1027	1050	23
Red rock	1050	1082	32
Oil sand	1082	1096	14

No. 24.—Stringer No. 13. Producers Oil Co. Elevation, 1195. Depth, 1051. Drilling finished Mar. 1, 1912. Plate VIII, A.

	Feet		
	From	To	Thickness
Soil	0	10	10
Red clay	10	35	25
Hard shale	35	50	15
Red shale	50	75	25
Lime	75	80	5
Red shale	80	102	22
Lime	102	106	4
Red shale	106	200	94
Lime	200	207	7

Blue slate	207	258	51
Hard lime	258	260	2
Oil sand	260	270	10
Lime	270	278	8
Sand, lime shell	278	300	22
Blue slate	300	350	50
Hard lime	350	355	5
Blue shale	355	375	20
Hard lime	375	377	2
Blue shale	377	390	13
Lime	390	395	5
Blue shale	395	400	5
Lime	400	402	2
Shale	402	427	25
Lime	427	433	6
Blue shale	433	439	6
Lime shell	439	441	2
Blue shale	441	453	8
Lime rock	453	456	3
Blue shale	456	495	39
Sand rock	495	497	2
Blue shale	497	505	8
Lime rock	505	507	2
Shale	507	510	3
Lime	510	515	5
Shale, oil	515	548	33
Lime	548	551	3
Blue shale	551	555	4
Lime	555	557	2
Blue shale	557	624	67
Lime	624	632	8
Blue shale	632	712	80
Lime	712	714	2
Red shale	714	725	11
Gumbo	725	755	30
Lime	755	757	2
Blue shale	757	800	43
Shale and shells	800	810	10
Oil sand	810	820	10
Gumbo	820	826	6
Red rock	826	840	14
Blue shale	840	860	20
Gumbo	860	870	10
Blue shale	870	890	20
Red shale	890	934	44
Rock	934	937	3
Red shale	937	950	13

Blue shale and red mud	950	960	10
Oil sand.............	960	972	12
Red shale............	972	1000	28
Dry sand and shale...	1000	1035	35
Oil sand.............	1035	1045	10
Sand rock............	1045	1051	6

No. 25.—Stringer No. 14. Producers Oil Co. Elevation, 1193. Depth, 1081. Drilling commenced Jan. 18, 1912. Drilling finished Feb. 17, 1912. 250 feet of 12 1-2-inch casing; 533 feet of 10-inch casing. A strong gasser at first, but did not last. Plates VIII, A, and XI, A.

	Feet		
	From	To	Thickness
Red mud............	0	60	60
Water sand..........	60	68	8
Red and blue shale...	68	140	72
Water sand..........	140	145	5
Red shale and mud...	145	250	105
Sand, oil show.......	250	270	20
Light blue shale......	270	330	60
Sand, gas show.......	330	340	10
Red and blue mud....	340	380	40
Sand, gas show.......	380	390	10
Blue shale...........	390	440	50
Sand, show oil.......	440	450	10
Red and blue shale...	450	505	55
Sand, good oil........	505	530	25
Red mud............	530	545	15
Oil sand, good........	545	550	5
Blue shale...........	550	570	20
Lime, sand gas.......	570	595	25
Blue shale and mud...	595	650	55
Gas sand, good.......	650	675	25
Blue shale and red mud	675	800	125
Light gray shale......	800	815	15
Red mud............	815	825	10
Red mud and blue shale	825	945	120
Lime shell and sand..	945	963	18
Oil sand.............	963	980	17
Red mud............	980	1035	55
Oil sand.............	1035	1060	25
Lime shell...........	1060	1065	5
Red mud............	1065	1081	16

No. 26.—Stringer No. 19. Producers Oil Co. Elevation, 1190. Depth, 1078. Drilling commenced Feb. 19, 1912. Drilling finished

March 7, 1912. 723 feet of 10-inch casing; 965 feet of 8-inch casing; 120 feet of 6-inch casing. Plates VIII, A, XI, B, and XII, B.

	Feet		
	From	To	Thickness
Blue clay	0	60	60
Lime	60	66	6
Red rock	66	300	234
Sand, show oil	300	330	30
Red rock	330	340	10
Water sand	340	360	20
Red rock	360	460	100
Lime	460	465	5
Blue clay	465	475	10
Red rock	475	690	215
Water sand	690	725	35
Red rock	725	755	30
Blue clay	755	825	70
Red rock	825	900	75
Lime	900	905	5
Red rock	905	965	60
Oil sand	965	986	21
Red rock	986	1024	38
Oil sand	1024	1051	27
Red rock	1051	1066	15
Oil sand	1066	1078	12

No. 27.—Stringer No. 12. Producers Oil Co. Elevation, 1198. Depth, 958. Drilling commenced Dec. 4, 1911. Drilling finished Jan. 22, 1912. Pumping 150 barrels. Plate VIII, B.

	Feet		
	From	To	Thickness
Red and blue mud	0	450	450
Gas shell	450	455	5
Blue and red mud	455	505	50
Oil sand	505	525	20
Blue and red mud	525	575	20
Dry sand	575	580	5
Blue and red mud	580	800	220
Oil and gas sand	800	815	15
Red mud	815	830	15
Blue shale	830	860	30
Red mud	860	920	60
Sandy shale	920	940	20
Oil sand	940	956	16
Shale	956	958	2

No. 28.—Stringer No. 17. Producers Oil Co. Elevation, 1198. Drilling. Plate VIII, B.

	Feet		
	From	To	Thickness
Red rock	0	20	20
Blue slate	20	40	20
Lime	40	55	15
Blue slate	55	95	40
Blue slate	95	185	90
Red rock	185	190	5
Lime	190	200	10
Red rock	200	225	25
Gas sand	225	232	7
Blue slate	232	250	18
Red rock	250	280	30
Sand, oil	280	285	5
Red rock	285	365	80
Blue shale	365	380	15
Red rock	380	435	55
Blue slate	435	455	20
Sand, gas	455	463	8
Red rock	463	480	17
White slate	480	495	15
Lime	495	530	35
Red rock	530	545	15
Lime	545	555	10
Blue slate	555	575	20
Lime	575	582	7
Blue slate	582	610	28
Slate and shells	610	660	50
Sand	660	670	10
Blue slate	670	725	55
Red rock	725	730	5
Sand and slate	730	745	15
White slate	745	755	10
Lime	755	770	15
Blue slate	770	790	20
Red rock	790	795	5
White slate	795	800	5
Red rock	800	820	20
Sand	820	830	10
Red rock	830	850	20
Lime	850	885	35
Blue shale	885	895	10
Red rock	895	905	5
Lime shell	905	910	5
Red rock	910	925	15

Sand	925	952	27
Red rock	952	976	24
Sand	876	992	16
Red rock	992	1030	38
Sand	1030	1048	18
Red rock	1048	1065	17
Lime	1065	1075	10
Red rock	1075	1085	10
Lime	1085	1120	35
Blue slate	1120	1178	58
Lime	1178	1185	7
Slate	1185	1200	15
Sand	1200	1210	10
Lime	1210	1225	15
Sand, water	1225	1240	15
Slate	1240	1260	20
Sand	1260	1270	10
Red rock	1270	1275	5
Sand	1275	1280	5
Red rock	1280	1300	20
Blue shale	1300	1310	10
White shale	1310	1325	15

No. 29.—Stringer No. 10. Producers Oil Co. Elevation, 1195. Depth, 1053. 204 feet of 12 1-2-inch casing; 379 feet of 10-inch casing; 926 feet of 8-inch casing; 1008 feet of 6-inch casing. Flowing 75 barrels. Plates VIII, B, X, A, and XII, A.

		Feet	
	From	To	Thickness
Red rock	0	80	80
Blue shale	80	200	120
Red rock	200	225	25
Blue shale	225	315	90
Shale and rock	315	350	35
Lime shell, gas	350	352	2
Brown shale	352	367	15
Lime shell, gas	367	370	3
Blue shale	370	405	35
Red rock	405	430	25
Lime shell	430	434	4
Blue shale	434	444	10
Lime shell	444	449	5
Blue shale	449	510	61
Broken sand and shale	510	518	8
Oil sand	518	542	24
Blue gumbo	542	560	18
Sand shell	560	600	40

Mud and shale rock	600	870	270
Lime shell	870	873	3
Blue shale	873	883	10
Shale and rock	883	930	47
Gas sand	930	935	5
Oil sand	935	960	25
Gyp rock	960	964	4
Blue shale	964	969	5
Red rock	969	994	25
Sand and shale	994	1010	16
Lime	1010	1012	2
Blue slate	1012	1030	18
Sand shale	1030	1037	7
Sand	1037	1043	6
Red cave	1043	1053	10

No. 30.—Stringer No. 16. Producers Oil Co. Elevation, 1197. Depth, 537. Drilling commenced Jan. 11, 1912. Drilling finished Jan. 31, 1912. 250 feet of 8 1-4-inch casing; 517 feet of 6 5-8-inch casing. Flowing 100 barrels. Plate VIII, B.

	Feet		
	From	To	Thickness
Red mud	0	55	55
Sand shells	55	57	2
White mud	57	65	8
Red shale	65	90	25
White shale	90	115	25
Red shale	115	235	120
White shale	235	251	16
Shell	251	252	1
White shale	252	272	20
Red shale	272	322	50
Shell, gas	322	323	1
Sandy shale	323	366	43
Red mud	363	401	35
White shale	401	476	75
Red shale	476	501	25
White shale	501	517	16
Oil sand	517	537	20

No. 31.—Stringer No. 11. Producers Oil Co. Elevation, 1193. Depth, 540. Drilling commenced Nov. 10, 1911. Drilling finished Dec. 8, 1911. 518 feet of 8-inch casing. 50 barrels. Plate VIII, B.

	Feet		
	From	To	Thickness
Red rock	0	80	80
Blue shale	80	105	25

Red rock	105	225	120
Blue shale	225	245	20
Red rock	245	285	40
Blue shale	285	315	30
Red rock	315	350	35
Lime shell gas	350	352	2
Brown shale	352	367	15
Lime shell gas	367	370	3
Blue shale	370	405	35
Red rock	405	430	25
Lime shell	430	434	4
Blue shale	434	444	10
Lime shell	444	449	5
Blue shale	449	510	51
Broken shale	510	520	10
Oil sand	520	540	20

No. 32.—Stringer No. 9. Producers Oil Co. Elevation, 1193. Depth, 1061. Drilling commenced Sept. 29, 1911. Drilling finished Oct. 25, 1911. 974 feet of 8-inch casing; 1061 feet of 4-inch casing. Flowing 200 barrels. Plates VIII, B, and X, B.

		——Feet——	
	From	To	Thickness
Clay	0	15	15
Sand, clay, gravel	15	45	30
Shell	45	46	1
Hard red pack sand	46	66	20
Packed gravel	66	91	25
Shell	91	231	140
Hard sand	231	234	3
Shale and rock	234	281	47
Hard sand, oil	281	303	22
Red clay	303	343	40
Shell rock	343	346	3
Hard shale	346	396	50
Shale and rock	396	464	68
Shell	464	466	2
Hard clay	466	482	16
Boulders	482	486	4
Shell	486	498	12
Boulders	498	504	6
Hard clay	504	524	20
Hard sand	524	541	17
Hard lime	541	549	8
Hard shale	549	600	51
Hard shell	600	614	14
Gravel and boulders	614	622	8

Hard shale...........	622	642	20
Rock and boulders....	642	646	4
Sand, shale, shells....	646	786	140
Hard shale...........	786	861	75
Rock, gas, sand.......	861	869	8
Shell	869	911	42
Shale	911	941	30
Rock	941	946	5
Hard shell, sand, rock.	946	958	12
Sand	958	962	4
Shale	962	965	3
Sand	965	975	10
Shale	975	1002	27
Shale and sand.......	1002	1015	13
Hard sand...........	1015	1040	25
Gumbo	1040	1042	2
Hard sand...........	1042	1046	4
Shale	1046	1048	2
Hard sand...........	1048	1061	13

No. 33.—Stringer No. 21. Producers Oil Co. Elevation, 1190. Depth, 1061. Drilling commenced Aug. 24, 1911. Drilling finished Oct. 3, 1911. 960 feet of 8-inch casing; 1061 feet of 6-inch casing. Flowing 60 barrels. Plate VIII, B.

		Feet	
	From	To	Thickness
Red clay............	0	26	26
Rock	26	30	4
Rock and gravel......	30	38	8
Rock and shale.......	38	429	391
Sand, oil............	429	434	5
Rock	434	437	3
Hard shale...........	437	445	8
Rock	445	451	6
Shale and gumbo.....	451	470	19
Hard shale...........	470	490	20
Rock	490	513	23
Hard shale...........	513	521	8
Rock	521	523	2
Shale	523	528	5
Rock	528	547	19
Shale	547	553	6
Rock	553	554	1
Hard shale...........	554	598	44
Gumbo	598	646	48
Shale and rock.......	646	652	6
Hard sand...........	652	658	6

Hard shale	658	662	4
Sand rock	662	672	10
Gumbo	672	707	35
Rock and boulders	707	710	3
Shale	710	715	5
Gumbo	715	720	5
Shale	720	727	7
Rock and boulders	727	730	3
Gumbo	730	776	46
Rock and boulders	776	790	14
Gumbo	790	800	10
Rock and gumbo	800	819	19
Hard sand, oil	819	824	5
Hard shale	824	834	10
Gumbo	834	870	36
Shale, gumbo, rock	870	960	90
Hard oil sand	960	987	27
Shale and boulders	987	1017	30
Sand rock	1017	1021	4
Shale	1021	1029	8
Hard oil sand	1029	1061	32

No. 34.—Stringer No. 7. Producers Oil Co. Elevation, 1190. Depth, 1061. Drilling commenced Aug. 24, 1911. Drilling finished Oct. 3, 1911. Top of oil sand lies at 1029 feet. Plates VIII, B, and XI, A.

No. 35.—Stringer No. 2. Producers Oil Co. Elevation, 1189. Depth, 987. Drilling commenced July 8, 1911. Drilling finished Aug. 3, 1911. 30 feet of 10-inch casing; 806 feet of 8 1-4-inch casing; 960 feet of 6-inch casing. Flowing. Plate VIII, B.

	——Feet——		
	From	To	Thickness
Clay	0	14	14
Gravel	14	18	4
Blue shale	18	160	142
Red gumbo	160	270	110
Shale and thin strata oil sand	270	330	60
Blue and red shale	330	400	70
White rock	400	406	6
Blue shale	406	510	104
White sand and sheets of hard rock	510	530	20
Blue shale	530	544	14
Oil sand	544	558	14
Hard blue lime	558	563	5

Shale	563	635	72
Gray crystal rock	635	640	5
Hard shale	640	680	40
Oil sand	680	687	7
Red gumbo	687	722	35
White rock	722	730	8
Gumbo	730	806	76
Oil sand	806	822	16
Shale	822	828	6
Oil sand	828	840	12
Shale	840	850	10
Mixed shale	850	960	110
Oil sand	960	985	25
Mixed shale	985	987	2

No. 36.—Stringer No. 5. Producers Oil Co. Elevation, 1189. Depth, 1074. Flowing 500 barrels. Plate VIII, B.

		Feet	
	From	To	Thickness
Surface clay	0	14	14
Sand and gravel	14	32	18
Clay	32	44	12
Gravel	44	52	8
Hard gravel	52	64	12
Hard red clay and boulders	64	144	80
Shale and boulders	144	284	140
Hard sand	284	300	16
Red clay	300	320	20
Hard sand	320	356	36
Clay and boulders	356	396	40
Rock	396	399	3
Clay	399	419	20
Rock	419	420	1
Hard shale	420	460	40
Rock and boulders	460	464	4
Red clay	464	494	30
Hard shale and boulders	494	514	20
Hard boulders water	514	530	16
Hard gumbo	530	555	25
Hard shale	555	595	40
Rock and boulders	595	611	16
Hard shale	611	641	30
Rock	641	645	4
Hard shale	645	665	20
Hard clay	665	675	10
Hard sand oil	675	688	13

Hard shale and clay	688	722	34
Rock	722	726	4
Hard shale	726	806	80
Hard sand	806	821	15
Hard red clay	821	841	20
Rock	841	845	4
Hard red clay	845	865	20
Rock and boulders	865	873	8
Hard red clay	873	908	35
Rock	908	912	4
Hard red clay	912	958	46
Hard sand	958	975	17
Hard red clay	975	990	15
Hard sand and boulders	990	1000	10
Hard shale	1000	1035	35
Hard sand	1035	1072	37
Shale	1072	1074	2

No. 37.—Stringer No. 3. Producers Oil Co. Elevation, 1189. Depth, 1063. Drilling commenced July 12, 1911. Drilling finished Sept. 13, 1911. 64 feet of 12 1-2-inch casing; 250 feet of 10-inch casing; 523 feet of 8-inch casing; 824 feet of 6 1-2-inch casing; 1045 feet of 5 3-16-inch casing. Flowing 450 barrels. Plate VIII, B.

		Feet	
	From	To	Thickness
Red mud	0	80	80
Lime shell	80	90	10
Red mud	90	140	50
Blue shale	140	150	10
Brown mud	150	220	70
Red mud	220	270	50
Sand oil	270	274	4
Blue shale	274	290	16
Oil sand	290	295	5
Red mud	295	335	40
Blue shale and sand, gas	335	360	25
Blue shale	360	370	10
Lime shell	370	380	10
Blue shale and shells	380	400	20
Red mud	400	420	20
Salt water	420	435	15
Blue shale	435	450	15
Red mud	450	460	10
Blue shale	460	515	55
Salt sand	515	523	8

Blue shale	523	570	47
Red mud	570	580	10
Blue shale	580	660	80
Red mud	660	665	5
Gas	665	670	5
Blue slate	670	700	30
Lime	700	710	10
Blue shale	710	730	20
Red mud	730	824	94
Sand	824	834	10
Red mud	834	870	36
Blue shale	870	950	80
Red mud	950	970	20
Sand	970	980	10
Blue shale	980	1024	44
Sand	1024	1063	39

No. 38.—Stringer No. 6. Producers Oil Co. Elevation, 1189. Depth, 1048. Flowing 60 barrels. Plates VIII, B, and XII, B.

		Feet	
	From	To	Thickness
Red clay	0	36	36
Rock	36	40	4
Shale	40	77	37
Hard shale	77	83	6
Rock	83	84	1
Hard shale	84	128	44
Rock	128	131	3
Shale	131	143	12
Rock	143	145	2
Shale	145	269	124
Rock	269	273	4
Shale	273	288	15
Hard sand, oil	288	306	18
Hard shale	306	325	19
Rock	325	329	4
Hard red shale	329	365	36
Rock	365	370	5
Hard shale	370	380	10
Rock	380	383	3
Shale	383	390	7
Rock and boulders	390	410	20
Hard shale	410	433	23
Rock	433	435	2
Hard shale	435	450	15
Rock	450	452	2
Hard shale	452	463	11

Rock	463	464	1
Shale	464	502	38
Rock and boulders	502	527	25
Shale	527	566	39
Rock and boulders	566	575	9
Shale	575	595	20
Rock	595	600	5
Shale and shell	600	625	25
Gumbo	625	630	5
Shale	630	635	5
Hard rock	635	648	13
Shale	648	663	15
Rock	663	669	6
Hard shale and boulders	669	686	17
Hard sand, oil	686	756	70
Shale and rock	756	820	64
Sand rock	820	825	5
Gumbo	825	964	139
Shale and rock	964	967	3
Sand	967	972	5
Shale	972	1030	58
Sand	1030	1048.	18

No. 39.—Stringer No. 1. Producers Oil Co. Elevation, 1187. Depth, 1906. Drilling commenced May 19, 1911. Drilling finished Aug. 19, 1911. 1477 feet of 6-inch liner; 1869 feet of 4-inch liner; 1866 feet of 2 1-2-inch tubing; 40 feet of 4-inch tubing. Plates VIII, B, and XI, B.

		Feet	
	From	To	Thickness
Red clay	0	35	35
Gravel and clay	35	45	10
Shale	45	270	225
Sand and shale, show oil	270	295	25
Blue shale	295	325	30
Sand and shale, show of oil	325	340	15
Blue gumbo	340	350	10
Hard shell	350	351	1
Shale and flint shell	351	580	229
Sand, show of oil	580	605	25
Blue shale	605	645	40
Hard white rock	645	652	7
Hard shale	632	683	31
Broken oil sand	683	723	40
Gumbo and red shale	723	1037	314

Hard white sand......	1037	1050	13
Blue gumbo.........	1050	1062	12
Oil sand, some soft...	1062	1070	8
Gumbo	1070	1107	37
White sand..........	1107	1140	33
Gumbo	1140	1157	17
Sand rock...........	1157	1161	4
Shale	1161	1178	17
Hard sand...........	1178	1192	14
Gumbo	1192	1260	68
Gray sand...........	1260	1272	12
Gumbo	1272	1314	42
Sand, show of oil.....	1314	1325	11
Gumbo (thin sand)...	1325	1430	105
Hard sand...........	1430	1440	10
Gumbo	1440	1465	25
Hard sand (set 6 inch at 1467)	1465	1469	4
Hard shale...........	1469	1478	9
Hard lime shell.......	1478	1482	4
Gumbo	1482	1511	29
Oil sand.............	1511	1537	26
Blue shale...........	1537	1547	10
Lime rock...........	1547	1555	8
Blue shale...........	1555	1612	57
Lime rock...........	1612	1615	3
Blue shale...........	1615	1635	20
Hard rock, light......	1635	1640	5
Blue shale...........	1640	1660	20
Lime rock...........	1660	1662	2
Blue shale...........	1662	1667	5
Lime rock...........	1667	1684	17
Blue shale...........	1684	1727	43
Lime rock...........	1727	1736	9
Blue shale...........	1736	1754	18
Oil sand.............	1754	1778	24
Lime shell...........	1778	1783	5
White mud..........	1783	1803	20
Hard lime...........	1803	1823	20
Oil sand.............	1823	1843	20
White sand and mud..	1843	1853	10
White mud..........	1853	1860	7
Lime rock...........	1860	1869	9
Shale	1869	1873	4
Hard red mud........	1873	1882	9
Sand and breaks of shale	1882	1906	24

No. 40.—Stringer No. 4. Producers Oil Co. Elevation, 1198. Depth, 1960. Drilling commenced Aug. 10, 1911. Drilling finished Jan. 5, 1912. 43 feet 6 inches of 10-inch casing; 1673 feet of 6-inch drive; 1855 feet of 4-inch line. Plate VIII, B.

		Feet	
	From	To	Thickness
Soil	0	4	4
Sand rock	4	70	66
Blue shale	70	115	45
Lime rock	115	120	5
Blue shale	120	126	6
Red shale	126	307	181
Oil sand	307	312	5
Blue shale	312	353	41
Red shale	353	365	12
Blue gumbo	365	385	20
Shells and gumbo	385	395	10
Hard lime	395	400	5
Blue gumbo	400	415	15
Lime rock	415	417	2
Gumbo	417	430	13
Lime shells	430	436	6
Dry sand	436	440	4
Blue shale	440	459	19
Hard lime	459	462	3
Blue shale	462	478	16
Hard lime	478	482	4
Blue shale	482	540	58
Gumbo and shells	540	550	10
Blue shale and lime shells	550	562	12
Red and blue shale	562	594	32
Sand	594	610	16
Blue shale	610	635	25
Gumbo and shells	635	687	52
Lime rock	687	693	6
Red shale	693	740	47
Sand, oil	740	765	25
Blue gumbo	765	770	5
Sand	770	775	5
Blue slate	775	787	12
Blue shale	787	825	38
Red rock	825	835	10
Blue shale	835	855	20
Red gumbo	855	865	10
Red shale and rock	865	910	45
Blue shale	910	930	20

Red shale	930	960	30
Sand, light	960	965	5
Hard red shale	965	975	10
Blue shale	975	1037	62
Lime rock	1037	1041	4
Red shale	1041	1082	41
Gyp gumbo	1082	1103	21
Blue shale	1103	1124	21
Shale and gumbo	1124	1165	41
Lime and sand	1165	1180	15
Hard blue slate	1180	1230	50
Lime and sand	1230	1250	20
Gumbo and rock	1250	1296	46
Sand rock	1296	1312	16
Hard lime	1312	1320	8
Blue shale and shells	1320	1340	20
Red and blue shale	1340	1420	80
Lime and shells, sand rock	1420	1436	16
White gyp	1436	1444	8
Red and blue shale	1444	1505	61
Lime shell	1505	1507	2
Gumbo	1507	1510	3
Lime shell	1510	1512	2
Blue shale and shells	1512	1545	33
Gyp	1545	1564	19
Blue shale	1564	1580	16
Lime shells	1580	1582	2
Shale and gumbo	1582	1600	18
Hard rock	1600	1610	10
Gumbo and gyp	1610	1630	20
Blue shale	1630	1641	11
Soft lime	1641	1653	12
Gumbo	1653	1657	4
Sand and shale	1657	1662	5
Gumbo	1662	1668	6
Lime rock	1668	1670	2
Blue shale	1670	1695	25
Soft lime	1695	1700	5
Blue shale	1700	1718	18
Hard lime	1718	1720	2
Soft white lime	1720	1730	10
Gumbo	1730	1738	8
Hard lime	1738	1741	3
Gumbo	1741	1753	12
Lime rock	1753	1770	17
White gumbo	1770	1775	5

Lime rock	1775	1812	37
Blue shale	1812	1822	10
Lime rock	1822	1830	8
Red shale	1830	1840	10
Blue shale	1840	1855	15
Oil sand	1855	1869	14
Sand and shale	1869	1872	3
Oil sand	1872	1877	5
Sand and shale	1877	1879	2
Oil sand	1879	1882	3
Shale and sand	1882	1886	4
Dry sand	1886	1895	9
Oil sand	1895	1905	10
Dark blue shale	1905	1925	20
Hard white lime	1925	1942	17
Oil sand	1942	1958	16
Dry sand	1958	1959	1
White mud	1959	1960	1

No. 41.—McBurney No. 1. Producers Oil Co. Elevation, 1196. Depth, 815. Drilling commenced Sept. 24, 1911. Drilling finished Feb. 3, 1912. 161 feet 6 inches of 12 1-2-inch casing; 516 feet 6 inches of 10-inch casing; 717 feet of 8-inch casing; 814 feet of 6-inch casing. Flowing 275 barrels. Plate VIII, B.

		Feet	
	From	To	Thickness
Red mud	0	90	90
Blue shale	90	130	40
Red mud	130	150	20
Oil, sand	150	157	7
Blue shale	157	190	33
Red mud	190	250	60
Blue shale	250	275	25
Red mud	275	350	75
Sand shale	350	360	10
Red mud	360	400	40
Blue shale	400	440	40
Sandy lime (oil)	440	460	20
Blue shale	460	485	25
Red rock	485	500	15
Blue shale	500	650	150
Red mud	650	690	40
Blue shale	690	740	50
Red shale	740	812	72
Oil, sand	812	815	3

No. 42.—Sheldon No. 1. Corsicana Petroleum Co. Elevation, 1201. Depth, 843. Drilling commenced September 23, 1911. Drilling finished October 11, 1911. Producing well. Plate IX, A.

	Feet		
	From	To	Thickness
Soil	0	15	15
Red rock	15	65	50
Showing oil, sand	65	75	10
Blue clay	75	110	35
Red rock	110	331	221
Blue clay	331	375	44
Red rock	375	425	50
Gas and oil, sand	425	450	25
Blue clay	450	550	100
Red rock	550	635	85
Oil, sand	635	655	20
Blue clay	655	670	15
Limestone	670	680	10
Blue clay	680	755	75
Hard lime	755	780	25
Oil and gas, sand	780	805	25
Red rock	805	820	15
Lime rock	820	830	10
Red rock	830	835	5
Oil, sand	835	843	8

No. 43.—Sheldon No. 1. McBride. Elevation, 1189. Depth, 1743. Producing well.

No. 44.—Cross & Brown No. 9. Corsicana Petroleum Co. Depth, 1230. Drilling commenced January 25, 1912. Drilling finished February 28, 1912. 360 feet of 12 1-2-inch casing; 874 feet of 10-inch casing; 1209 feet of 8-inch casing. This well is one of the few dry holes in the proven field, and is surrounded by producing wells. Plate IX, A.

	Feet		
	From	To	Thickness
Red rock	0	130	130
Lime shell	130	132	2
Red rock	132	350	218
Blue shale	350	445	95
Sand, oil	445	451	6
Red and blue shale	451	515	64
Sand, soft white	515	521	6
Blue and white shale	521	632	111
Lime shells	632	642	10

Red rock	642	670	28
Lime shells	670	776	116
Blue shale and red rock	776	945	169
Sand, oil and gas	945	950	5
Blue shale and red rock	950	1190	240
Sand, oil	1190	1195	5
Blue sand, shale	1195	1225	30
Sand, hole full of salt water	1225	1230	5

No. 45.—Cross & Brown No. 6. Corsicana Petroleum Co. Depth, 969. Drilling commenced January 10, 1912. Drilling finished February 10, 1912. 340 feet of 12 1-2-inch casing; 805 feet of 10-inch casing; 951 feet of 8 14-inch casing. This well started with a production of 250 barrels a day. Plate IX, A.

	Feet		
	From	To	Thickness
Soil	0	10	10
White shale	10	20	10
Red shale	20	170	150
Sand	170	180	10
White shale	180	220	40
Red rock	220	310	90
White shale	310	340	30
Red rock	340	430	90
Sand, oil	430	460	30
Red rock	460	515	55
Sand	515	530	15
Red rock	530	640	110
Sand, gas	640	650	10
Brown and red rock	650	790	140
Sand	790	805	15
Brown and red shale	805	905	100
Sand, small gas	905	930	25
Brown shale	930	949	19
Oil sand, good	949	969	20
Oil sand, pay	951	969	18

No. 46.—Cross & Brown No. 7. Corsicana Petroleum Co. Depth, 969. Drilling commenced January 12, 1912. Drilling finished February 6, 1912. 355 feet of 12 1-2-inch casing; 830 feet of 10-inch casing; 937 feet of 8-inch casing; 60 feet of 6 5-8-inch casing.

	Feet		
	From	To	Thickness
Red rock	0	76	76
Blue clay	76	95	19

Red rock	95	105	10
Lime	105	115	10
Red rock	115	180	65
Lime shells	180	190	10
Red rock	190	320	130
Blue clay	320	490	170
Sand, oil	490	500	10
Red rock	500	540	40
Lime	540	545	5
Red rock	545	640	95
Blue clay	640	670	30
Red rock	670	730	60
Blue clay	730	765	35
Red rock	765	790	25
Lime	790	800	10
Red rock	800	850	50
Blue clay	850	875	25
Red rock	875	895	20
Blue clay	895	915	20
Red rock	915	937	22
Oil sand, pay	937	943	6
Slate	943	954	11
Oil, sand	954	976	22

No. 47.—Hamilton No. 9. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1194. Depth, 970. Drilling commenced November 21, 1911. Drilling finished December 26, 1911. Oil sand 522 to 540. Oil sand 946 to 970. Cased in sand. Plates IX, A, X, A, and XII, A.

No. 48.—Hamilton No. 10. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1191. Depth, 1010. Drilling commenced December 4, 1911. Drilling finished December 22, 1911. Oil sand 980 to 996. Drilled to 1010, plugged back to 996 and put on the pump. Plate X, A.

No. 49.—Hamilton No. 11. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1186. Depth, 990. Drilling commenced December 6, 1911. Drilling finished December 30, 1911. Oil sand 830. Oil sand 952 to 980. Drilled to 990, plugged back to 980 and put on the pump. Plate X, A.

No. 50.—Hamilton No. 12. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1183. Depth, 974. Drilling commenced January 5, 1912. Drilling finished January 29, 1912. Gas sand 930 to 935. Oil sand 951 to 974. Plate X, A.

No. 51.—Hamilton No. 7. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1180. Depth, 1024. Drilling commenced

October 12, 1911. Drilling finished November 2, 1911. Oil sand 996 to 1024. Plate X, A.

No. 52.—Hamilton No. 13. Sold by Red River Oil Co. to Corsicana Petroleum Co. Depth 540.

No. 53.—Hamilton No. 6. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1192. Depth, 1050. Drilling commenced October 9, 1911. Drilling finished November 14, 1911. Oil sand 945 to 970. Broken sand 1000 to 1012. Total depth in red rock 1050. Plate IX, A.

No. 54.—Hamilton No. 8. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1179. Depth, 1015. Drilling commenced November 8, 1911. Drilling finished December 3, 1911. Oil sand 988 to 1007. Red rock 1007 to 1015. Plate IX, B.

No. 55.—Hamilton No. 2. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1191. Depth, 1039. Drilling commenced August 23, 1911. Drilling finished September 7, 1911. Oil sand 533 to 553. Oil sand 959 to 978. Drilling was begun again October 10, 1911. Oil sand 1000 to 1020. Big pay sand 1020 to 1039. Plates IX, A, and X, B.

No. 56.—Hamilton No. 1. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1188. Depth, 974½. Drilling commenced July 21, 1911. Drilling finished August 7, 1911. Showing oil 60 feet. Small gas 70 feet. Gas sand 787 to 800 feet. Oil sand 950 to 974 feet 6 inches. Plates X, B, and XII, A.

No. 57.—Hamilton No. 3. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1185. Depth, 990. Drilling commenced August 31, 1911. Drilling finished September 17, 1911. Water sand 20 to 23. Oil sand 957 feet 6 inches to 978 feet 6 inches. Drilling was begun again November 9, 1911. Good sand to 990. Stopped in red rock at 990. Plate X, B, and XII, A.

No. 58.—Hamilton No. 4. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1180. Depth, 1125. Drilling commenced September 20, 1911. Drilling finished October 10, 1911. Oil sand 997 to 1014. Salt water at 1020. Oil sand at 1038 feet 6 inches. Salt water at 1125. Plugged back to 1040 and put on the pump. Plate X, B.

No. 59.—Hamilton No. 5. Sold by Red River Oil Co. to Corsicana Petroleum Co. Elevation, 1180. Depth, 1018. Drilling commenced September 21, 1911. Drilling finished October 5, 1911. Oil sand 1012 to 1018. Stopped in good sand. Plates IX, B, and X, B.

No. 60.—Putnam No. 9. Corsicana Petroleum Co. Elevation, 1189. Depth, 1037. Drilling commenced September 11, 1911. Drilling finished October 27, 1911. 40 feet of 10-inch casing: 547 feet of 8-inch casing; 955 feet of 6-inch casing; 1037 feet of 4-inch casing. This well came in flowing 400 barrels. Plate IX, A.

		Feet	
	From	To	Thickness
Red mud and clay	0	16	16
Gravel and water	16	19	3
Lime shell	19	22	3
Dark sand	22	41	19
Sand rock	41	51	10
Blue gumbo	51	63	12
Hard sand	63	70	7
Broken lime	70	80	10
Red mud	80	87	7
Blue shale	87	204	117
Sand rock	204	215	11
Broken sand	215	274	59
Soft sand	274	294	20
Gypsum	294	311	17
Lime rock	311	315	4
Blue shale	315	325	10
Gypsum rock	325	329	4
Sand oil	329	340	11
Lime rock	340	346	6
Red and blue shale	346	361	15
Soft sand	361	376	15
Red mud and boulders	376	390	14
Black slate	390	402	12
Red mud	402	424	22
Lime rock	424	430	6
Broken slate	430	435	5
Hard lime	435	439	4
Red mud	439	445	6
Sand rock	445	449	4
Blue and red shale	449	468	19
Lime rock	468	472	4
Blue gumbo	472	482	10
Hard blue slate	482	491	9
Sand Rock	491	495	4
Red shale	495	500	5
Hard lime	500	511	11
Red and blue shale	511	521	10
Sand rock	521	528	7
Blue shale	528	536	8

Sand, oil	536	546	10
Hard lime	546	550	4
Red and blue shale	550	590	40
Sand rock	590	600	10
Blue slate	600	621	21
Hard sand	621	625	4
Broken shelly rock	625	641	16
Red gumbo	641	662	21
Hard slate	662	668	6
Sand rock	668	686	18
Blue shale	686	700	14
Red gumbo	700	722	22
Shale and broken rock	722	783	61
Sand rock	783	797	14
Shale and mud	797	816	19
Hard sand	816	821	5
Red and blue mud	821	856	35
Red and blue shale	856	874	18
Hard lime	874	880	6
Blue shale	880	902	22
Red mud	902	910	8
Red and blue shale	910	946	36
Red gumbo	946	955	9
Oil sand	955	968	13
Blue gumbo	968	970	2
Broken rock and shale	970	1011	41
Oil sand	1011	1015	4
Gypsum rock	1015	1018	3
Oil sand	1918	1024	6
Gypsum rock	1024	1030	6
White talc	1030	1033	3
Oil, sand	1033	1037	4

No. 61.—Putnam No. 8. Corsicana Petroleum Co. Elevation, 1187. Depth, 990. Drilling commenced August 26, 1911. Drilling finished September 20, 1911. Plate XI, A.

		Feet	
	From	To	Thickness
Red clay and sand	0	16	16
Red mud and gravel (water)	16	26	10
Red shale and mud	26	76	50
Shelly rock	76	81	5
Red shale	81	270	189
Gravel and hard shale	270	280	10
Flint rock	280	284	4

Red gumbo	284	290	6
Lime shell	290	292	2
Hard shale and boulders	292	300	8
Red gumbo	300	314	14
Lime rock	314	317	3
Shale and boulders	317	327	10
Hard shale	327	350	23
Hard lime shell	350	355	5
Hard shell rock	355	374	19
Hard dark shale	374	380	6
Hard bed boulders	380	383	3
Red shale	383	396	13
Hard boulders	396	399	3
Hard shale and shelly rock	399	415	16
Red gumbo	415	425	10
Lime rock	425	428	3
Red gumbo	428	435	7
Gumbo and shelly rock	435	500	65
Hard shale and shelly rock	500	507	7
Lime rock	507	510	3
Sand rock	510	515	5
Hard shale and lime shells	515	521	6
Gypsum rock	521	525	4
Sand rock	525	529	4
Shale and boulders	529	531	2
Sand rock	531	537	6
Hard shale	537	551	14
Boulders and shale	551	584	33
Sand rock	584	588	4
Red and blue shale	588	636	48
Lime rock	636	639	3
Hard shale	639	690	51
Blue gumbo	690	719	29
Lime shell	719	721	2
Blue shale	721	735	14
Blue gumbo	735	750	15
Red and blue shale	750	800	50
Gas, sand	800	806	6
Red and blue gumbo	806	817	11
Hard shale	817	825	8
Red gumbo, tough	825	845	20
Red and blue shale	845	961	116
Oil, sand	961	990	29

No. 62.—Putnam No. 11. Corsicana Petroleum Co. Elevation, 1185. Depth, 1008. Drilling commenced September 27, 1911. Drilling finished October 28, 1911. 48 feet of 10-inch casing; 978 feet of 8-inch casing; 1008 feet of 4-inch casing. Plate XI, A.

	Feet		
	From	To	Thickness
Red clay	0	16	16
Gravel, water	16	26	10
Red mud and gravel	26	80	54
Sand, oil trace	80	83	3
Red mud and gravel	83	326	243
Hard lime	326	329	3
Red mud and boulders	329	367	38
Hard lime	367	370	3
Red mud	370	390	20
Hard lime	390	393	3
Red mud	393	425	32
Hard lime	425	427	2
Red mud and boulders	427	528	101
Hard lime	528	534	6
Blue gumbo	534	546	12
Red mud and boulders	546	552	6
Sand rock, oil	552	557	5
Water, sand	557	562	5
Hard lime	562	570	8
Red mud boulders	570.	620	50
Red and blue shale	620	745	125
Hard lime	745	748	3
Blue and red shale	748	790	42
Lime rock	790	792	2
Blue and red shale	792	798	6
Lime rock	798	799	1
Blue and red shale	799	824	25
Red mud and boulders	824	892	68
Red and blue shale	892	978	86
Broken sand	978	983	5
Oil sand, open	983	1000	17
Red mud	1000	1008	8

No. 63.—Putnam No. 12. Corsicana Petroleum Co. Elevation, 1181. Depth, 1023. Drilling commenced October 10, 1911. Drilling finished November 16, 1911. 84 feet of 10-inch casing; 1006 feet of 8-inch casing; 18 feet of 6-inch perforated. Initial production 125 barrels. Plates XI, A, and XII, A.

	Feet		
	From	To	Thickness
Red mud	0	16	16
Water, sand	16	24	8
Red clay	24	52	28
Mud and shale	52	88	36
Sand, oil	88	95	7
Sand and boulders	95	109	14
Shelly rock and shale	109	153	44
Lime rock	153	160	7
Mud and gravel	160	203	43
Shell, rock and shale	203	267	64
Mud and boulders	267	285	18
Hard shale	285	309	24
Red gumbo	309	340	31
Lime rock	340	342	2
Shale and shelly rock	342	354	12
Blue gumbo	354	358	4
Hard sand, oil	358	383	25
Blue gumbo and boulders	383	394	11
Lime rock	394	398	4
Blue gumbo	398	400	2
Hard lime	400	403	3
Mud and boulders	403	415	12
Lime rock	415	421	6
Blue mud and gravel	421	433	12
Dark hard slate	433	446	13
Hard lime	446	452	6
Blue gumbo	452	464	12
Hard lime	464	467	3
Blue gumbo	467	479	12
Lime rock	479	481	2
Red mud and shale	481	517	36
Dry sand	517	529	12
Blue gumbo	529	537	8
Lime rock	537	544	7
Gumbo and boulders	544	567	23
Hard sand, trace	567	591	24
Blue gumbo and boulders	591	623	32
Sand, oil	623	644	21
Blue gumbo and sand	644	660	16
Lime rock	660	673	13
Blue gumbo	673	747	74
Lime rock	747	750	3
Blue gumbo	750	770	20

Lime rock...........	770	772	2
Shale and sand.......	772	780	8
Gumbo and shale.....	780	820	40
Sand, oil............	820	836	16
Blue gumbo..........	836	850	14
Hard sand...........	850	854	4
Blue gumbo..........	854	897	43
Hard slate...........	897	909	12
Lime rock...........	909	917	8
Blue gumbo..........	917	937	8
Blue gumbo..........	917	937	20
Blue shale...........	937	955	18
Blue gumbo..........	955	976	21
Red and blue shale...	976	988	12
Shale and dry salt.....	988	1006	18
Oil sand.............	1006	1022	16
Red mud............	1022	1023	1

No 64.—Putnam No. 10. Corsicana Petroleum Co. Elevation, 1188. Depth, 1065. Drilling commenced Sept. 26, 1911. Drilling finished Oct. 27, 1911. 42 feet of 10-inch casing; 815 feet of 8-inch casing; 1065 feet of 6-inch casing. Plate IX, A.

		Feet	
	From	To	Thickness
Red clay............	0	16	16
Water gravel.........	16	28	12
Red clay and gravel...	28	45	17
Oil sand.............	45	63	18
Red and blue shale....	63	79	16
Sand, oil............	79	85	6
Red and blue shale....	85	195	110
Red gumbo..........	195	210	15
Blue and red shale....	210	285	75
Sand and gravel......	285	290	5
Red and blue shale...	290	315	25
Lime rock...........	315	317	2
Blue and red shale....	317	335	18
Red gumbo..........	335	355	20
Red and blue shale....	355	393	38
Lime rock...........	393	396	3
Red and blue shale....	396	406	10
Red gumbo..........	406	439	33
Lime rock...........	439	442	3
Red and blue shale...	442	453	11
Lime rock...........	453	455	2
Red and blue shale...	455	465	10

Red gumbo..........	465	495	30
Red and blue shale...	495	505	10
Lime rock...........	505	517	12
Red and blue shale...	517	531	14
Broken sand, oil......	531	555	24
Blue gumbo.	555	557	2
Lime rock...........	557	559	2
Blue gumbo..........	559	565	6
Red and blue shale....	565	600	35
Blue gumbo..........	600	615	15
Red and blue shale....	615	635	20
Hard lime...........	635	638	3
Red and blue shale....	638	680	42
Sand rock...........	680	690	10
Red and blue gumbo..	690	726	36
Lime shell...........	726	730	4
Red and blue shale...	730	740	10
Blue gumbo..........	740	750	10
Red and blue shale...	750	758	8
Tough red gumbo....	758	767	9
Red and blue shale....	767	780	13
Red gumbo..........	780	805	25
Red and blue shale....	805	813	8
Oil sand.............	813	815	2
Red and blue shale...	815	865	50
Lime rock...........	865	867	2
Red and blue shale...	867	877	10
Red gumbo	877	892	15
Red and blue shale....	892	910	18
Red gumbo..........	910	916	6
Red and blue shale...	916	974	58
Oil sand.............	974	993	19
Red and blue shale...	993	1032	39
Sand rock, dry.......	1032	1055	23
Oil sand.............	1055	1065	10

No. 65.—Putnam No. 4. Corsicana Petroleum Co. Elevation, 1187. Depth, 1077. Plates IX, A, and XI, A.

	Feet		
	From	To	Thickness
Surface	0	12	12
Gravel	12	18	6
Red mud............	18	45	27
Sand showing oil......	45	71	26
Red mud.............	71	85	14
Oil sand.............	85	90	5
Red mud and boulders.	90	115	25

Oil sand.............	115	121	6
Red mud............	121	129	8
Hard shell...........	129	131	2
Red shale............	131	151	20
Hard shell...........	151	155	4
Red shale...........	155	171	16
Red mud and boulders.	171	192	21
Hard shell...........	192	196	4
Red mud............	196	210	14
Oil sand	210	218	8
Red mud and boulders.	218	236	18
Gravel and mud......	236	244	8
Red mud............	244	261	17
Oil sand.............	261	284	23
Red mud............	284	289	5
Mud and gravel......	289	299	10
Hard rock...........	299	304	5
Red mud............	304	326	22
Hard rock...........	326	328	2
Blue mud............	328	346	18
Blue mud and boulders	346	380	34
Hard rock...........	380	388	8
Red mud............	388	409	21
Oil sand.............	409	432	23
Blue mud............	432	448	16
Hard shell...........	448	452	4
Blue mud and boulders	452	472	20
Hard rock...........	472	474	2
Red and blue mud....	474	484	10
Hard shell...........	484	488	4
Blue mud...........	488	509	21
Hard lime rock.......	509	518	9
Blue and red shale...	518	545	27
Sand rock............	545	556	11
Blue gumbo..........	556	576	20
Blue and red shale...	576	584	8
Red gumbo..........	584	597	13
Blue and red shale...	597	622	25
Blue gumbo..........	622	626	4
Hard flint...........	626	635	9
Blue shale...........	635	655	20
Hard shell...........	655	658	3
Blue and red shale...	658	663	5
Hard sand rock......	663	678	15
Red gumbo..........	678	684	6
Blue shale...........	684	716	32
Hard rock...........	716	719	3

Blue and red shale....	719	754	35
Red mud and boulders.	754	810	56
Red and blue shale...	810	817	7
Sand rock...........	817	822	5
Gumbo and boulders..	822	855	33
Blue shale...........	855	872	17
Hard rock...........	872	878	6
Blue and red shale....	878	900	22
Blue gumbo and boulders	900	915	15
Sand rock...........	915	921	6
Blue mud and gravel..	921	945	24
Shale and gravel......	945	972	27
Oil sand.............	972	989	17
Blue slate............	989	996.	7
Blue gumbo..........	996	1022	26
Water sand..........	1022	1033	11
Gypsum rock.........	1033	1048	15
Oil sand.............	1048	1076	28
Red and blue gumbo..	1076	1077	1

No. 66.—Putnam No. 2. Corsicana Petroleum Co. Elevation, 1187. Depth, 985. Drilling commenced May 31, 1911. Drilling finished June, 1911. Plate IX, A.

	Feet		
	From	To	Thickness
Soil and clay.........	0	40	40
Red mud............	40	50	10
Sand rock...........	50	80	30
Red mud............	80	183	103
Hard rock...........	183	187	4
Red mud............	187	294	107
Hard rock...........	294	300	6
Blue mud............	300	314	14
Boulders	314	375	61
Sand, show oil.......	375	381	6
Gumbo	381	405	24
Hard rock...........	405	419	14
Gumbo	419	430	11
Hard shell rock......	430	455	25
Gumbo	455	474	19
Mixed mud..........	474	509	35
Hard rock...........	509	522	13
Gumbo	522	553	31
Hard rock...........	553	562	9
Shell rock...........	623	629	6
Gumbo	629	684	55

Hard rock	684	694	10
Gumbo	694	724	30
Hard rock	724	728	4
Gumbo	728	764	36
Hard rock	764	773	9
Shale	773	803	30
Hard rock	803	807	4
Gypsum and gumbo	807	864	57
Shale	864	904	40
Gypsum and gumbo	904	964	60
Shale	964	974	10
Sand oil	974	985	11

No. 67.—Putnam No. 18. Corsicana Petroleum Co. Depth, 992. Drilling commenced Feb. 5, 1912. Drilling finished March 11, 1912. 336 feet 5 inches of 12 1-2-inch casing; 828 feet 10 inches of 10-inch casing; 980 feet of 8-inch casing. Plate IX, A.

	Feet		
	From	To	Thickness
Brown soil	0	15	15
Red shale	15	100	85
Sand	100	105	5
White slate	105	150	45
Red shale	150	235	85
White slate	235	275	40
Sand, oil show	275	285	10
White shale	285	300	15
Red shale	300	340	40
Sand, oil	340	360	20
White shale	360	400	40
Red shale	400	410	10
Brown shale	410	521	111
Sand, salt	521	550	29
Brown shale	550	600	50
White shale	600	674	74
Red shale	674	678	4
Sand, oil and gas	678	708	30
Sand, oil and water	708	715	7
Red rock	715	732	17
White shale	732	810	78
Red shale	810	828	18
Hard lime	828	831	3
White slate	831	837	6
Red rock	837	880	43
Sand, oil	880	883	3
Red rock	883	980	97
Sand oil	980	990	10
Shale	990	992	2

No. 68.—Putnam No. 5. Corsicana Petroleum Co. Elevation, 1187. Depth, 1089. Drilling commenced Aug. 1, 1911. Drilling finished Sept. 23, 1911. Plates IX, A, and XII, B.

	——	Feet ——	
	From	To	Thickness
Red sand and clay....	0	8	8
Brown slate..........	8	16	8
Quicksand (water)....	16	23	7
Red mud............	23	63	40
Red mud and boulders.	63	80	17
Sand, trace of oil.....	80	83	3
Red mud............	83	88	5
Hard shelly rock......	88	90	2
Brown slate and mud.	90	130	40
Red mud and gravel..	130	210	80
Red gumbo..........	210	274	64
Hard shelly rock.....	274	278	4
Red mud and gravel...	278	287	9
Sand showing oil.....	287	309	22
Red and blue shale...	309	317	8
Red mud............	317	327	10
Blue mud, thin shells..	327	337	10
Dry sand rock.......	337	361	24
Blue gumbo..........	361	370	9
Hard flint rock.......	370	371	1
Red and blue shale....	371	385	14
Lime rock...........	385	386	1
White talc...........	386	388	2
Lime shelly rock.....	388	396	8
Red and blue shale...	396	408	12
Flint rock...........	408	413	5
Tough red gumbo.....	413	418	5
Red and blue shale...	418	430	12
Blue gumbo..........	430	436	6
Hard flint rock.......	436	437	1
Red mud............	437	443	6
Blue gumbo and boulders	443	456	13
Lime rock	456	458	2
Shelly slate, dark.....	458	476	18
Red mud and shale...	476	515	39
Lime shell...........	515	517	2
Blue gumbo...........	517	526	9
Flint rock, hard......	526	532	6
Red mud and shale...	532	565	33
Hard dark slate......	565	585	20
Blue mud and shale...	585	637	52

Lime rock	637	639	2
Blue gumbo	639	645	6
Lime rock	645	655	10
Hard dark slate	655	679	24
Sand showing oil and gas	679	704	25
Red mud and shale	704	729	25
Hard dark slate	729	734	5
Flint rock	734	772	38
Gypsum rock	772	775	3
Blue gumbo	775	784	9
Red mud and boulders	784	821	37
Hard sand rock, dry	821	824	3
Blue gumbo	824	841	17
Dry sand	841	845	4
Blue mud and gravel	845	887	42
Dark hard slate	887	909	22
Red and blue shale	909	946	37
Red gumbo	946	964	18
Oil sand	964	970	6
White talc	970	972	2
Red mud and boulders	972	979	7
Oil sand	979	988	9
Red gumbo	988	995	7
Red mud and boulders	995	1023	28
Red gumbo	1023	1046	23
Gumbo and gravel	1046.	1055	9
Hard sand, dry	1055	1062	7
Oil sand	1062	1088	26
White talc	1088	1089	1

No. 69.—Putnam No. 3. Corsicana Petroleum Co. Elevation, 1200. Depth, 1901. This well was the first well drilled into the deep sand and had an initial production of 1600 barrels. Nine months later it was still flowing about 600 barrels. Plates IX, A, and XI, B.

	Feet		
	From	To	Thickness
Red sand and gravel	0	18	18
Hard sand	18	19	1
Red tough mud	19	27	8
Packed sand	27	43	16
Red shale and gravel	43	78	35
Brown slate and mud	78	100	22
Hard gravel and shells	100	112	12
Red mud	112	116	4
Mud and gravel	116	121	5

Flint stone shells.....	121	122	1
Red mud and gravel...	122	181	59
Flint shells..........	181	183	2
Red mud and gravel..	183	282	99
Broken sand rock.....	282	283	1
Red mud and gravel...	283	323	40
Shell rock...........	323	343	20
Red mud and gravel...	343	390	47
Broken sand, show oil.	390	396	6
Red shale...........	396	405	9
Hard rock...........	405	407	2
Broken shells, hard...	407	427	20
Hard flint rock.......	427	429	2
Red and blue shale...	429	444	15
Hard flint shell.......	444	445	1
Mud and gravel......	445	465	20
Hard flint shells......	465	466	1
Red mud and gravel...	466	485	19
Hard flint rock.......	485	486	1
Mud and gravel......	486	495	9
Hardest flint rock.....	495	496	1
Broken rock.........	496	502	6
Blue and red shale....	502	542	40
Broken shell.........	542	544	2
Red and blue shale...	544	560	16
Hard broken rock.....	560	577	17
Red and blue shale...	577	691	114
Hard broken rock....	691	701	10
Red and blue shale...	701	726	25
Oil sand, broken......	726	752	26
White talc...........	752	756	4
Oil sand, salt water and slate	756	780	24
Red and blue shale....	780	784	4
Hard flint shell.......	784	785	1
Red and blue shale...	785	850	65
Red mud and gravel...	850	887	37
Red and blue shale...	887	940	53
Red mud and boulders	940	960	20
Red and blue shale...	960	1049	89
Sand, show oil.......	1049	1057	8
Red and blue gumbo...	1057	1069	8
Red mud and boulders	1069	1108	39
Blue gumbo and fine sand	1108	1112	4
Red mud and gravel...	1112	1180	68
Water sand..........	1180	1195	15

Blue gumbo and boulders	1195	1220	25
Hard broken water sand rock	1220	1267	47
Blue gumbo and boulders	1267	1318	51
Water sand	1318	1326	8
Blue gumbo and boulders	1326	1340	14
Hard sand rock	1340	1348	8
Blue mud and boulders	1348	1369	21
Red joint clay	1369	1389	20
Red mud and gravel	1389	1445	56
Red hard boulder	1445	1449	4
Red and blue mud and gravel	1449	1469	20
Red and blue shale	1469	1505	36
Blue gumbo and boulders	1505	1526	21
Hard sand	1526	1530	4
Soft blue shale and mud	1530	1549	19
Hard flint rock	1549	1551	2
Blue shale	1551	1568	17
Hard flint rock	1568	1570	2
Soft blue shale	1570	1602	32
Oil sand, tested	1602	1607	5
White talc	1607	1609	2
Red mud	1609	1617	8
Hard red and blue shale	1617	1620	3
Hard flint	1620	1622	2
Blue shale	1622	1638	16
Shelly rock	1638	1639	1
Hard cavey shale	1639	1655	16
Blue gumbo and sand, possibly water	1655	1663	8
Brown shale	1663	1683	20
Blue gumbo and boulders	1683	1696	13
Blue shale	1696	1704	8
Hard flint	1704	1707	3
Hard gumbo	1707	1715	8
Red shale	1715	1729	14
Sand, trace of oil	1729	1731	2
Blue gumbo	1731	1735	4
Blue and red shale	1735	1780	45
Hard flint rock	1780	1790	10
Soft rock	1790	1791	1

Hard flint rock	1791	1802	11
Blue gumbo	1802	1806	4
Hard flint rock	1806	1808	2
Soft blue gumbo	1808	1809	1
Hard flint	1809	1811	2
Hard black slate	1811	1840	29
Dark blue gumbo and boulders	1840	1848	8
Red and blue shale	1848	1859	11
Hard cap rock	1859	1861	2
Porous, oil rock and fossil (tested)	1861	1867	6
Hard rock	1867	1869	2
Hard black slate	1869	1885	16
Red mud and gravel	1885	1887	2
Blue gumbo and boulders	1887	1890	3
Oil sand, good	1890	1901	11

No. 70.—Putnam No. 1. Corsicana Petroleum Co. Elevation, 1186. Depth, 1629. Drilling commenced Oct., 1910. Drilling finished April, 1911. Plates IX, A, and XII, B.

	Feet		
	From	To	Thickness
Soil	0	7	7
Sand rock	7	33	26
Red mud	33	101	68
Sand rock	101	107	6
Red mud	107	171	64
Sand rock	171	177	6
Red mud	177	256	79
Sand rock	256	283	27
Red mud	283	317	34
Sand rock	317	334	17
Red mud	334	365	31
Sand rock	365	386	21
Sand, show oil	386	388	2
Shale	388	392	4
Hard sand rock	392	394	2
Shale	394	408	14
Shells	408	412	4
Red mud	412	428	16
Hard flint rock	428	431	3
Mixed mud	431	453	22
Hard rock	453	455	2
Mixed mud and boulders	455	484	29

Mixed mud	484	504	20
Shale	504	512	8
Mixed mud	512	519	7
Rock and shells	519	532	13
Mixed mud	532	575	43
Hard rock and shells	575	582	7
Blue shale	582	623	41
Red mud	623	633	10
Hard slate	633	646	13
Hard rock and shells	646	659	13
Shale	659	693	34
Sand rock	693	708	15
Shell and rock	708	713	5
Mud and shale	713	899	186
Mixed mud and boulders	899	948	49
Mixed mud	948	969	21
Hard rock	969	973	4
Shale and mud	973	991	18
Shale	991	1004	13
Sand, show oil	1004	1008	4
Mud and boulders	1008	1038	30
Sand, show oil	1038	1060	22
Mud and boulders	1060	1070	10
Gypsum and sand	1070	1103	33
Red mud	1103	1106	3
Mud and boulders	1106	1116	10
Hard slate	1116	1138	22
Sand, show oil	1138	1163	25
Blue mud and shale	1163	1176	13
Hard rock	1176	1178	2
Blue mud and boulders	1178	1192	14
Gypsum	1192	1207	15
Hard rock	1207	1213	6
Gypsum and gumbo	1213	1224	11
Hard rock	1224	1227	3
Shell rock	1227	1243	16
Mixed gumbo and sand	1243	1264	21
Hard sand rock	1264	1286	22
Gypsum and gumbo	1286	1347	61
Hard sand rock	1347	1352	5
Hard rock and shale	1352	1375	23
Gumbo	1375	1383	8
Shale	1383	1395	12
Gumbo	1395	1404	9
Hard rock	1404	1407	3
Shale	1407	1432	25

Hard shell rock	1432	1440	8
Gumbo	1440	1465	25
Rock	1465	1469	4
Gumbo	1469	1477	8
Shell rock	1477	1485	8
Shale	1485	1494	9
Gumbo	1494	1503	9
Rock and shale	1503	1515	12
Gumbo	1515	1531	16
Sand, show oil and gas	1531	1543	12
Shale	1543	1547	4
Gumbo	1547	1567	20
Shale	1567	1582	15
Gumbo	1582	1598	16
Hard flint rock	1598	1601	3
Gumbo	1601	1616	15
Shale, oil	1616	1622	6
Oil	1622	1628	6

No. 71.—Putnam No. 6. Corsicana Petroleum Co. Elevation, 1195. Depth, 1973.

No. 72.—Putnam No. 15. Corsicana Petroleum Co. Elevation, 1198. Depth, 1078. Drilling commenced Nov. 14, 1911. Drilling finished Dec. 25, 1911. 39 feet of 10-inch casing; 1053 feet of 8 1-4-inch casing. Plates XI, A, and XII, A.

	Feet		
	From	To	Thickness
Red soil	0	5	5
Yellow sand	5	8	3
Red and blue mud	8	16	8
Sand rock	16	19	3
Red shale	19	39	20
Red and blue shale	39	75	36
Slate and lime shale	75	83	8
Red and blue shale	83	110	27
Oil sand	110	114	4
Red and blue shale	114	122	8
Sand rock, oil	122	135	13
Red and blue shale	135	200	65
Red gumbo	200	215	15
Red and blue shale	215	260	45
Hard shale and slate	260	264	4
Red gumbo	264	289	25
Slate and shale	289	294	5
Red gumbo	294	310	16
Red and blue shale	310	360	50

Red gumbo..........	360	375	15
Lime shell...........	375	381	6
Red and blue shale...	381	426	45
Hard blue and red shale and lime shells.....	426	444	18
Red and blue shale....	444	464	20
Lime rock	464	468	4
Red and blue shale...	468	491	23
Lime shell...........	491	494	3
Red and blue shale....	494	515	21
Lime shell...........	515	517	2
Red and blue shale...	517	550	33
Lime shell...........	550	555	5
Red and blue shale...	555	577	22
Hard lime rock.......	577	594	17
Red and blue shale...	594	600	6
Lime rock...........	600	605	5
Red gumbo..........	605	630	25
Oil sand.............	630	636	6
Red gumbo..........	636	654	18
Lime shell...........	654	657	3
Hard red and blue shale	657	686	29
Red gumbo..........	686	700	14
Hard red and blue shale	700	710	10
Lime rock...........	710	721	11
Red and blue shale....	721	756	35
Red gumbo..........	756	771	15
Lime shell...........	771	775	4
Red and blue shale....	775	820	45
Red gumbo..........	820	838	18
Lime shell...........	838	844	6
Red and blue shale....	844	884	40
Red gumbo..........	884	896	12
Oil sand.............	896	900	4
Red gumbo..........	900	906	6
Lime rock...........	906	911	5
Red and blue shale...	911	971	60
Lime rock...........	971	977	6
Red and blue shale...	977	1022	45
Red gumbo..........	1022	1044	22
Blue shale...........	1044	1053	9
Oil sand.............	1053	1070	17
Blue shale...........	1070	1078	8

No. 73.—Waggoner No. 16. Producers Oil Co. Elevation, 1192. Depth, 1950. Initial production flowing 200 barrels. Plate VIII, A Figure 8.

Samples examined: 1840-1846. A white compact limestone, containing small bivalves and some dark organic fragments often large but indistinct. Some dark grey limestone with many fossil fragments and marcasite. Fusulina, Fenestella and a coral (?) were noted in this dark rock.

	Feet		
	From	To	Thickness
Red clay	0	11	11
Hard lime	11	13	2
Sand rock	13	56	43
Blue shale	56	81	25
Lime rock	81	83	2
Hard blue shale	83	104	21
Lime rock	104	106	2
Blue shale	106	109	3
Lime rock	109	115	6
Blue shale	115	133	18
Rock	133	137	4
Red shale	137	170	33
Lime rock	170	176	6
Blue shale	176	240	64
Lime rock	240	245	5
Blue shale	245	267	22
Lime rock	267	271	4
Blue shale, sand	271	285	14
Lime rock	285	292	7
Shale and gumbo	292	322	30
Red rock	322	326	4
Blue shale	326	362	36
Chalk	362	368	6
Lime rock	368	369	1
Gumbo	369	406	37
Blue shale	406	413	7
Red shale	413	440	27
Lime rock	440	446	6
Shale	446	457	11
Lime rock	457	459	2
Blue shale	459	466	7
Sand and shale	466	471	5
Lime and water sand	471	480	9
Blue shale	480	530	50
Sand rock	530	540	10
Red shale	540	551	11
Hard white lime	551	556	5
Hard blue shale	556	661	105
Lime rock	661	673	12
Gyp and lime	673	682	9

Blue shale...........	682	709	27
Sand rock, oil........	709	723	14
Blue and white shale..	723	729	6
Soft sand, rock, oil....	729	744	15
Hard white gyp.......	744	752	8
Soft sand, oil........	752	769	17
Red gumbo..........	769	803	34
Hard sand, oil.......	803	809	6
Blue and white shale..	809	868	59
Sand rock, oil........	868	876	8
Blue shale...........	876	906	30
Sand rock, oil........	906	913	7
Blue shale...........	913	940	27
Red rock and boulders	940	1009	69
Blue shale...........	1009	1017	8
Gumbo	1017	1050	33
White lime..........	1050	1057	7
White sand..........	1057	1062	5
Blue shale...........	1062	1096	34
Hard white sand......	1096	1103	7
Blue shale...........	1103	1133	30
Slate and shale.......	1133	1156	23
Hard lime...........	1156	1161	5
Soft white sand.......	1161	1174	13
Shale and slate.......	1174	1210	36
Red and white shale...	1210	1240	30
White sand water.....	1240	1261	21
Red shale...........	1261	1311	50
Sand water..........	1311	1342	31
Shale and gumbo.....	1342	1375	33
Red gumbo..........	1375	1404	29
Hard lime...........	1404	1408	4
Red gumbo..........	1408	1421	13
Blue shale and boulders	1421	1450	29
Red gumbo boulders..	1450	1469	19
Sand rock	1469	1476	7
Blue shale...........	1476	1480	4
Hard white sand......	1480	1485	5
Soft brown sand......	1485	1490	5
Shale and boulders....	1490	1510	20
Lime rock...........	1510	1513	3
Gumbo	1513	1540	27
Lime rock...........	1540	1543	3
Blue shale...........	1543	1565	22
Blue and white gumbo	1565	1582	17
Sand rock...........	1582	1586	4

Gumbo and shale	1586	1593	7
Sand rock	1593	1598	5
Shale and boulders	1598	1621	23
Blue and red shale	1621	1634	13
Lime rock	1634	1641	7
Blue gumbo	1641	1692	51
Shale and boulders	1692	1709	17
Lime rock	1709	1715	6
Red shale	1715	1745	30
White rock	1745	1751	6
Lime and gyp	1751	1801	50
Blue lime	1801	1803	2
Shale and boulders	1803	1840	37
White lime	1840	1851	11
Red and blue shale	1851	1857	6
Brown sand rock	1857	1859	2
Blue shale	1859	1864	5
Sand rock oil	1864	1879	15
White lime and gyp	1879	1886	7
Oil sand	1886	1917	31
Blue shale	1917	1931	14
Oil sand	1931	1950	19

No. 74.—Waggoner No. 8. Producers Oil Co. Elevation, 1202. Depth, 1949. Drilling commenced September 14, 1911. Drilling finished November 30, 1911. Flowing 200 barrels. Plate VIII, B.

	Feet		
	From	To	Thickness
Red clay	0	30	30
Sand rock	30	61	31
Blue shale	61	68	7
White lime	68	76	8
Slate and shale	76	121	45
Sand rock	121	137	16
Hard white lime	137	140	3
Red and blue shale	140	205	65
Red mud and clay	205	280	75
Sand and shale	280	307	27
Blue and white shale	307	350	43
Soft red clay	350	405	55
Hard red rock	405	407	2
Blue shale	407	460	53
Hard white lime	460	490	30
Hard blue shale	490	507	17
Hard rock, slate	507	535	28
Hard blue shale	535	552	17

Gumbo and boulders..	552	580	28
Hard lime rock......	580	587	7
Blue gumbo..........	587	616	29
White lime...........	616	620	4
Red rock..............	620	654	34
Blue shale............	654	668	14
Hard red rock........	668	684	16
Hard boulders.........	684	698	14
Blue white lime........	698	703	5
Hard white rock......	703	710	7
Soft sand rock........	710	733	23
Red and blue shale....	733	755	22
Blue shale............	755	764	9
Sand rock............	764	784	20
Sand rock............	784	788	4
Sand rock............	788	801	13
Red and blue shale....	801	870	69
Blue shale............	870	895	25
Red and blue shale....	895	934	39
White rock...........	934	938	4
Gumbo and boulders...	938	978	40
Red and blue shale....	978	1021	43
Hard white rock.......	1021	1023	2
Gumbo and boulders...	1023	1053	30
Sand rock............	1053	1069	16
Hard blue gumbo......	1069	1093	24
Blue slate............	1093	1113	20
Sand rock............	1113	1117	4
Soft sand rock........	1117	1133	16
Shaly gumbo............	1133	1155	22
Hard red rock.........	1155	1171	16
Red and blue shale....	1171	1191	20
Hard blue gumbo......	1191	1231	40
Red and blue shale....	1231	1253	22
White sand rock......	1253	1268	15
Shale and boulders....	1268	1303	35
Hard blue shale.......	1303	1324	21
Soft white rock........	1324	1329	5
White sand rock.......	1329	1364	35
Blue and red gumbo...	1364	1382	18
Hard lime rock.......	1382	1387	5
Hard blue shale.......	1387	1407	20
White lime rock.......	1407	1409	2
Hard blue gumbo	1409	1421	12
Shale boulders........	1421	1446	25
Hard red rock.........	1446	1451	5
Shale boulders........	1451	1468	17

Red and blue gumbo...	1468	1490	22
Blue and white shale..	1490	1508	18
Sand rock............	1508	1515	7
Red and blue shale....	1515	1539	24
White and red rock....	1539	1548	9
Blue shale	1548	1573	25
Red and white rock...	1573	1578	5
Blue shale............	1578	1597	19
Brown and white rock	1597	1603	6
Blue and white shale..	1603	1629	26
Sand rock............	1629	1643	14
Red rock.............	1643	1647	4
Blue gumbo...........	1647	1656	9
Blue shale............	1656	1660	4
Hard red rock.........	1660	1671	11
Blue shale............	1671	1690	19
White rock...........	1690	1693	3
Blue and red shale....	1693	1723	30
Hard white and red rock	1723	1727	4
Red and blue shale....	1727	1730	3
White lime rock......	1730	1737	7
Gumbo and boulders...	1737	1749	12
Red and blue shale....	1749	1756	7
Blue and red gumbo...	1756	1767	11
Lime shale...........	1767	1785	18
Hard blue shale.......	1785	1793	8
Hard blue shale.......	1793	1812	19
Hard blue lime.......	1812	1844	32
Black shale...........	1844	1848	4
Lime and gyp.........	1848	1855	7
Hard black shale......	1855	1890	35
White shale...........	1890	1892	2
Lime and sand streaks	1892	1904	12
Blue shale............	1904	1920	16
Soft lime shale........	1920	1923	3
Sand rock............	1923	1949	26

No. 75.—Waggoner No. 9. Producers Oil Co. Elevation, 1196. Depth, 1968. Drilling commenced September 5, 1911. Drilling finished November 24, 1911. Flowing 300 barrels. Plates IX, A, and XI, B.

	Feet		
	From	To	Thickness
Red and blue shale......	0	135	135
Hard rock..	135	137	2
Shale	137	270	133
Shale (oil)..........	270	290	20

Red and blue shale....	290	590	300
Hard lime rock........	590	600	10
Gumbo and shale......	600	960	360
Broken oil, sand......	960	1000	40
Shale and gumbo......	1000	1150	150
Rock	1150	1160	10
Shale	1160	1250	90
Water, sand...........	1250	1280	30
Shale	1280	1425	145
Hard sand rock.......	1425	1431	6
Blue gumbo..........	1431	1660	229
Mixed shale...........	1660	1840	180
Rock and gumbo......	1840	1861	21
Lime rock............	1861	1868	7
Blue slate	1868	1882	14
Soft shale.............	1882	1887	5
Sand	1887	1888	1
Blue shale.............	1888	1917	29
Hard rock............	1917	1919	2
Gyp and lime..........	1919	1929	10
Blue shale............	1929	1934	5
Red shale.............	1934	1939	5
White mud............	1939	1946	7
Oil, sand.............	1946	1952	6
Limestone	1952	1960	8
Oil, sand.............	1960	1968	8

No. 76.—Waggoner No. 10. Producers Oil Co. Elevation, 1200. Drilling. Plates IX, B, and XI, B.

	Feet		
	From	To	Thickness
Red rock.............	0	90	90
Blue shale............	90	140	50
Shell	140	143	3
Blue shale............	143	175	32
Red shale............	175	185	10
Blue shale............	185	200	15
Red and blue shale.....	200	400	200
Lime shell............	400	406	6
Red shale.............	406	475	69
Blue shale............	475	500	25
White shale...........	500	535	35
Red shale............	535	600	65
Gray shale............	600	650	50
Red and blue shale....	650	1025	375
Gray shale...........	1025	1050	25
Sand, oil at top.......	1050	1075	25

Brown shale	1075	1095	20
Soft gumbo	1095	1155	60
Water, sand.	1155	1180	25
Gumbo	1180	1220	40
Sand	1220	1225	5
Hard gumbo	1225	1360	135
Hard sand	1360	1378	18
Gumbo	1378	1435	57
Hard sand	1435	1445	10
Gumbo	1445	1555	110
Hard sand	1555	1575	20
Gumbo	1575	1585	10
Lime rock	1585	1596	11
Gumbo	1596	1620	24
Shale lime and shells	1620	1640	20
Gumbo	1640	1660	20
Sand rock	1660	1665	5

No. 77.—Waggoner No. 11. Producers Oil Co. Elevation, 1208. Depth, 1089. Drilling commenced October 10, 1911. Drilling finished November 20, 1911. 1048 feet 8 inches of 8-inch line pipe. Plates IX, B, and XI, B.

		Feet	
	From	To	Thickness
Red clay	0	12	12
Water, sand	12	20	8
Red clay	20	26	6
Sand rock	26	36	10
Red shale	36	46	10
Sand rock	46	66	20
Blue shale	66	84	18
Lime rock	84	87	3
Blue shale and shells	87	130	43
Lime rock	130	132	2
Shale and shells	132	172	40
Lime rock	172	175	3
Blue shale	175	180	5
Lime rock	180	182	2
Shale and rock	182	260	78
Rock lime	260	265	5
Blue shale	265	285	20
Gumbo	285	300	15
Red shale	300	344	44
Rock lime	344	350	6
Blue shale	350	400	50
Red shale	400	436	36
Sand rock	436	441	5

Red shale	441	463	22
Gumbo	463	470	7
Rock lime	470	475	5
Gumbo	475	485	10
Rock lime	485	490	5
Blue shale	490	521	31
Sand	521	531	10
Red mud	531	545	14
Rock	545	546	1
Shale	546	553	7
Rock	553	554	1
Shale	554	563	9
Rock	563	564	1
Gumbo	564	578	14
Rock	578	579	1
Shale	579	617	38
Rock	617	619	2
Shale	619	636	17
Rock	636	640	4
Gumbo	640	643	3
Rock	643	644	1
Red mud	644	649	5
Gumbo	649	670	21
Sand rock	670	698	28
Gumbo	698	710	12
Shale	710	724	14
Sand rock	724	727	3
Shale	727	730	3
Rock	730	733	3
Shale	733	751	18
Rock	751	753	2
Gumbo	753	772	19
Sand rock	772	776	4
Gumbo	776	835	59
Shale	835	854	19
Rock	854	857	3
Shale	857	869	12
Rock	869	872	3
Shale	872	892	20
Sand rock	892	895	3
Shale	895	899	4
Sand rock	899	902	3
Shale	902	908	6
Gumbo	908	929	21
Hard red rock	929	1030	101
Red mud	1030	1034	4
Gumbo	1034	1038	4

Shale	1038	1045	7
Lime rock	1045	1050	5
Oil sand	1050	1088	38
Red mud	1088	1089	1

No. 78.—Waggoner No. 14. Producers Oil Co. Elevation, 1219. Drilling. Plate IX, B.

	Feet		
	From	To	Thickness
Red clay	0	20	20
Sand	20	40	20
Blue shale	40	75	35
Red shale	75	110	35
Shale and shells	110	210	100
Sand, oil	210	220	10
Shale and shells	220	480	260
Hard rock	480	485	5
Blue shale	485	500	15
Hard rock	500	505	5
Shale, shells and rock	505	615	110
Hard rock	615	623	8
Gumbo	623	670	47
Hard flint	670	674	4
Blue shale	674	750	76
Soft rock	750	763	13
Gumbo	763	830	67
Rock, sand, gas, oil	830	843	13
Gumbo	843	850	7
Hard lime rock	850	858	8
Red shale	858	873	15
Soft rock	873	903	30
Sand rock	903	914	11
Shale	914	922	8
Rock	922	926	4
Shale	926	947	21
Rock	947	957	10
Shale	957	994	37
Rock and boulders	994	1007	13
Shale	1007	1013	6
Rock	1013	1017	4
Shale	1017	1025	8
Rock	1025	1027	2
Shale	1027	1039	12
Hard lime	1039	1048	9

No. 79.—Waggoner No. 13. Producers Oil Co. Elevation, 1203. Drilling. Plate IX, B.

	Feet		
	From	To	Thickness
Red clay	0	87	87
Sand rock	87	125	38
Red rock	125	137	12
Sand rock	137	169	32
Red shale	169	173	4
Lime rock	173	197	24
Shale	197	211	14
Rock	211	229	18
Red shale	229	234	5
Lime rock	234	244	10
Hard shale	244	290	46
Shale and boulders	290	300	10
Shale	300	360	60
Hard rock	360	367	7
Shale	367	390	23
Rock	390	394	4
Shale	394	420	26
Rock	420	439	19
Shale and red rock	439	487	48
Hard lime	487	497	10
Shale and boulders	497	513	16
Lime rock	513	519	6
Shale	519	551	32
Lime rock	551	553	2
Shale and gumbo	553	624	71
Lime rock	624	625	1
Shale	625	629	4
Lime rock	629	631	2
Shale and boulders	631	639	8
Lime rock	639	642	3
Gumbo	642	647	5
Shale and gravel	647	668	21
Gumbo	668	690	22
Sand rock	690	700	10
Gumbo and gravel	700	731	31
Lime rock	731	732	1
Gumbo	732	752	20
Rock	752	772	20
Shale and red rock	772	830	58
Rock	830	839	9
Shale	839	985	146
Soft rock, sand streaks	985	1020	35
Shale	1020	1048	28
Rock	1048	1054	6
Hard sand, oil	1054	1066	12

Shale	1066	1090	24
Rock	1090	1095	5
Hard sand, oil........	1095	1100	5
Hard sand and boulders	1100	1122	22
Sand, oil.............	1122	1135	13
Hard sand rock.......	1135	1137	2
Hard sand, oil........	1137	1142	5
Hard sand rock.......	1142	1148	6
Gumbo	1148	1168	20
Hard salt sand........	1168	1179	11
Hard slate............	1179	1190	11
Hard sand and boulders	1190	1228	38
Rock	1228	1238	10
Gumbo	1238	1250	12
Rock	1250	1256	6
Shale	1256	1270	14
Rock	1270	1280	10
Hard shale...........	1280	1350	70
Hard sand, salt.......	1350	1356	6
Rock and boulders.....	1356	1364	8
Hard shale and rock...	1364	1390	26
Hard sand, salt.......	1390	1396	6
Rock	1396	1402	6
Hard shale...........	1402	1430	28
Rock	1430	1436	6
Shale	1436	1450	14
Rock and boulders....	1450	1458	8
Red gumbo...........	1458	1470	12
Soft shale............	1470	1480	10
Gumbo	1480	1521	41
Sand rock............	1521	1522	1
Gumbo and shale......	1522	1552	30
Rock	1552	1557	5
Hard shale...........	1557	1570	13
Soft shale............	1570	1591	21
Hard sand rock.......	1591	1596	5
Shale	1596	1613	17
Rock and boulders.....	1613	1627	14
Gumbo	1627	1634	7
Hard lime rock.......	1634	1639	5
Gyp and boulders......	1639	1670	31
Gumbo	1670	1685	15
Hard gyp.............	1685	1697	12
Gumbo and boulders...	1697	1715	18
Sand rock............	1715	1725	10
Gumbo	1725	1740	15

Lime rock	1740	1754	14
Sand rock	1754	1768	14
Shale	1768	....	..

No. 80.—Allen No. 5. Corsicana Petroleum Co. Elevation, 1178. Depth, 1011. Drilling commenced December 8, 1911. Drilling finished January 26, 1912. 350 feet of 12 1-2-inch casing; 795 feet of 10-inch casing; 990 feet of 9-inch casing. Plate XI, B.

	Feet		
	From	To	Thickness
Red rock	0	150	150
Blue clay	150	300	150
Sand, oil	300	320	20
Red rock	320	350	30
Blue clay	350	500	150
Lime shells	500	505	5
Blue clay	505	705	200
Red rock	705	790	85
Lime	790	795	5
Red rock	795	835	40
Sand, oil	835	855	20
Red rock	855	905	50
Blue clay	905	945	40
Lime	945	950	5
Red rock	950	975	25
Lime	975	980	5
Red rock	980	990	10
Oil, sand	990	1011	21

No. 81.—Allen No. 4. Corsicana Petroleum Co. Elevation, 1179. Depth, 1000. Drilling commenced November 14, 1911. Drilling finished December 7, 1911. 350 feet of 12 1-2-inch casing; 977 feet of 10-inch casing. Plates IX, A, and X, A.

	Feet		
	From	To	Thickness
Red rock	0	75	75
Blue clay	75	125	50
Red rock	125	180	55
Blue clay	180	225	45
Sand, oil	225	245	20
Blue clay	245	260	15
Red rock	260	325	65
Sand	325	340	15
Blue clay	340	345	5
Red rock	345	360	15
Sand	360	370	10

Blue clay	370	505	135
Sand	505	530	25
Red rock	530	575	35
Shells	575	580	5
Sand, oil	580	640	60
Blue clay	640	660	20
Red rock	660	680	20
Lime	680	704	24
Blue clay	704	720	16
Red rock	720	750	30
Lime	750	790	40
Blue clay	790	800	10
Lime	800	815	15
Blue clay	815	855	40
Sand, oil	855	880	25
Red rock	880	890	10
Shells	890	900	10
Blue clay	900	930	30
Red rock	930	945	15
Sand	945	955	10
Red rock	955	977	22
Sand	977	1000	23

No. 82.—Allen No. 3. Corsicana Petroleum Co. Elevation, 1178. Depth, 1043. Drilling commenced December 4, 1911. Drilling finished January 4, 1912. Plates IX, B, and X, B.

	Feet		
	From	To	Thickness
Red rock	0	80	80
Blue clay	80	130	50
Red rock	130	180	50
Sand, gas	180	190	10
Blue clay	190	240	50
Red rock	240	270	30
Lime	270	280	10
Red rock	280	335	55
Blue clay	335	365	30
Sand, oil	365	375	10
Blue clay	375	500	125
Sand	500	525	25
Blue clay	525	560	35
Shell and lime	560	575	15
Blue clay	575	600	25
Red rock	600	640	40
Lime and shells	640	655	15
Red rock	655	720	65
Sand	720	740	20

Blue clay	740	780	40
Red rock	780	805	25
Lime	805	820	15
Blue clay	820	880	60
Lime	880	890	10
Blue clay	890	925	35
Red rock	925	955	30
Lime	955	960	5
Sand	960	970	10
Blue clay	970	984	14
Sand, oil	984	986	2
Blue clay	986	999	13
Red rock	999	1020	21
Slate	1020	1023	2
Oil, sand	1023	1043	20

No. 83.—Allen No. 6. Corsicana Petroleum Co. Elevation, 1197. Depth, 1054. Drilling commenced January 10, 1912. Drilling finished March 2, 1912. 370 feet of 12 1-2-inch casing; 895 feet of 10-inch casing; 975 feet of 8-inch casing. Plates IX, B, and XI, A.

		Feet	
	From	To	Thickness
Red rock	0	61	61
Blue clay	61	90	29
Red rock	90	130	40
Blue clay	130	150	20
Red rock	150	210	60
Blue clay	210	290	80
Red rock	290	370	80
Blue clay	370	395	25
Sand, oil	395	400	5
Red rock	400	460	60
Lime	460	470	10
Blue clay	470	555	85
Lime	555	564	9
Blue clay	564	590	26
Red rock	590	640	50
Blue clay	640	658	18
Lime	658	670	12
Red rock	670	685	15
Lime	685	695	10
Blue clay	695	728	33
Lime	728	734	6
Red rock	734	746	12
Lime	746	753	7
Red rock	753	776	23

Blue clay	776	808	32
Lime	808	811	3
Blue clay	811	870	59
Red rock	870	900	30
Gas, sand	900	912	12
Blue clay	912	940	28
Red rock	940	975	35
Oil, sand	975	985	10
Blue clay	985	1020	35
Red rock	1020	1040	20
Oil, sand	1040	1054	14

No. 84.—Allen No. 1. Producers Oil Co. Elevation, 1202. Depth, 1088. Plates IX, B, XI, A, XII, A, and XII, B.

No. 85.—Allen No. 4. Producers Oil Co. Elevation, 1199. Depth, 1080. Plates XI, A, and XII, B.

No. 86.—Allen No. 7. Producers Oil Co. Elevation, 1190. Depth, 1090. Completed February 24, 1912. 106 feet of 12 1-2-inch casing; 675 feet of 10-inch casing; 875 feet of 8-inch casing; 942 feet of 6 5-8 inch casing. Pumping. Plates XI, A, and XII, B.

	Feet		
	From	To	Thickness
Red mud	0	100	100
Lime rock	100	103	3
Blue shale	103	108	5
Lime rock	108	111	3
Blue shale	111	210	99
Blue slate and sand	210	220	10
Gray shale	220	270	50
Lime rock	270	272	2
Red mud	272	340	68
Blue shale and sand	340	410	70
Lime rock	410	413	3
Red mud	413	460	47
Lime rock	460	461	1
Blue mud	461	520	59
Lime rock	520	524	4
Broken shale	524	620	96
Water, sand	620	628	8
Shale and lime shells	628	670	42
Lime rock	670	675	5
Shale and lime shells	675	740	65
Blue mud	740	790	50
Lime rock	790	793	3

Red mud	793	820	27
Lime rock	820	822	2
Red mud	822	856	34
Gray shale	856	876	20
Oil, sand	876	897	21
Red mud	897	910	13
Lime rock	910	912	2
Gray shale	912	942	30
Oil, sand	942	952	10
Blue and red shale	952	1053	101
Slate and sand, oil	1053	1070	17
Red mud	1070	1088	18
Water, sand	1088	1090	2

No. 87.—Allen No. 2. Producers Oil Co. Elevation, 1202. Depth, 1090. Plates IX, B, and XII, A.

No. 88.—Allen No. 6. Producers Oil Co. Elevation, 1196. Depth, 1071. Drilling completed February 18, 1912. 56 feet of 12 1-2-inch casing; 645 feet of 10-inch casing; 890 feet of 8-inch casing; 1052 feet of 6-inch casing. Pumping. Plates IX, B, and XII, A.

	Feet		
	From	To	Thickness
Red mud	0	10	10
Soft sand	10	24	14
Red mud	24	40	16
Sand rock	40	45	5
Red mud	45	100	55
Hard lime	100	105	5
Red mud	105	175	70
Blue shale	175	200	25
Red mud	200	375	175
Blue shale	375	405	30
Shale and sand	405	420	15
Red mud	420	500	80
Red and blue mud	500	580	80
Blue shale	580	620	40
Salt, sand	620	640	20
Gray shale	640	700	60
Blue and white mud	700	870	170
Blue shale	870	890	20
Oil, sand	890	900	10
Blue shale	900	910	10
Red mud	910	942	32
Oil, sand, poor	942	954	12
Blue shale	954	1015	61

Blue mud	1015	1055	40
Red and white mud	1055	1065	10
Red mud	1065	1071	6

No. 89.—Wilson and O'Byrne No. 1. Depth, 1650. Oil.

No. 90.—Home Oil Co. No. 1. Depth, 1140. Dry.

No. 91.—Woodruff No. 2. Corsicana Petroleum Co. Elevation, 1204. This well was drilling at a depth in excess of 2300 feet in March, 1912. The log to 2202 feet follows. Plate IX, B, and XI, B.

Samples examined: 2262. Dark greenish-gray shale, giving off sulphurous and bituminous fumes in a closed tube, slightly calcareous and fine in texture. With this were some fragments of gray and yellow limestone.

	Feet		
	From	To	Thickness
Sand, gravel and clay	0	20	20
Sand	20	45	25
Rock	45	50	5
Sand and gravel	50	90	40
Rock	90	100	10
Sand rock	100	110	10
Sand rock	110	125	15
Sand and gravel	125	165	40
Gumbo	165	170	5
Blue sand	170	183	13
Rock	183	187	4
Gumbo	187	190	3
Rock	190	193	3
Sand and gravel	193	240	47
Gumbo	240	250	10
Sand and gravel	250	300	50
Rock	300	308	8
Shale	308	325	17
Gumbo	325	340	15
Rock	340	345	5
Gumbo	345	350	5
Red shale	350	387	37
Sand rock	387	430	43
Gumbo	430	435	5
Rock	435	448	13
Red shale	448	460	12
Gumbo	460	465	5
Soapstone	465	475	10
Hard rock	475	477	2
Sand rock	477	490	13

Shell rock	490	492	2
Sand and shale	492	500	8
Hard rock	500	502	2
Gumbo	502	512	10
Hard rock	512	514	2
Gumbo	514	523	9
Shell rock	523	526	3
Hard gumbo	526	540	14
Rock	540	542	2
Gumbo	542	552	10
Rock	552	553	1
Shale and boulders	553	579	26
Rock	579	580	1
Gumbo and boulders	580	620	40
Sand shale, oil	620	625	5
Gumbo	625	635	10
Rock	635	643	8
Shale and boulders	643	653	10
Gumbo	653	660	7
Rock	660	665	5
Rock sand, oil	665	669	4
Soft shale	669	685	16
Sand rock	685	693	8
Shale and boulders	693	698	5
Shale	698	705	7
Gumbo	705	712	7
Sand rock	712	716	4
Shale	716	725	9
Rock	725	730	5
Gumbo and boulders	730	735	5
Shale	735	760	25
Rock	760	762	2
Gumbo	762	768	6
Rock	768	772	4
Rock	772	783	11
Gumbo	783	790	7
Shale	790	805	15
Gumbo	805	815	10
Hard shale	815	824	9
Rock	824	831	7
Sand shale	831	857	26
Gumbo	857	865	8
Rock	865	867	2
Shale	867	880	13
Gumbo	880	890	10
Rock	890	895	5
Hard sandy shale	895	910	15

Gumbo	910	917	7
Sand rock	917	940	23
Shale	940	952	12
Hard gumbo	952	980	28
Rock	980	981	1
Shale and boulders	981	1000	19
Gumbo	1000	1012	12
Shale	1012	1029	17
Shell rock	1029	1032	3
Gas, sand	1032	1033	1
Rock	1033	1034	1
Soft shale	1034	1040	6
Rock	1040	1042	2
Sand shale	1042	1052	10
Rock	1052	1054	2
Shale and boulders	1054	1064	10
Sand rock	1064	1080	16
Gumbo and boulders	1080	1088	8
Shale	1088	1125	37
Gumbo	1125	1133	8
Sand rock	1133	1153	20
Gypsum and gumbo	1153	1160	7
Hard rock	1160	1168	8
Shale and rock	1168	1175	7
Gumbo and boulders	1175	1185	10
Shale and boulders	1185	1190	5
Shale	1190	1200	10
Gumbo	1200	1218	18
Rock	1218	1220	2
Hard gumbo	1220	1230	10
Shale and gumbo	1230	1250	20
Shale and boulders	1250	1260	10
Shale	1260	1288	28
Rock	1288	1290	2
Gumbo	1290	1308	18
Rock	1308	1310	2
Sand rock	1310	1320	10
Shale and gumbo	1320	1340	20
Shale and boulders	1340	1350	10
Shale	1350	1370	20
Gumbo	1370	1380	10
Gumbo and boulders	1380	1390	10
Very hard rock	1390	1414	24
Soft sand rock	1414	1420	6
Gumbo	1420	1433	13
Rock	1433	1435	2
Sand rock	1435	1442	7

Shale	1442	1450	8
Hard gumbo	1450	1454	4
Shale	1454	1460	6
Gumbo	1460	1472	12
Rock	1472	1475	3
Shale	1475	1481	6
Sand rock	1481	1495	14
Shale	1495	1509	14
Rock	1509	1510	1
Blue shale	1510	1522	12
Sand rock	1522	1527	5
Shale	1527	1532	5
Rock	1532	1537	5
Shale and boulders	1537	1560	23
Gumbo	1560	1570	10
Sand rock	1570	1580	10
Hard shale	1580	1586	6
Chalk rock	1586	1591	5
Gumbo	1591	1600	9
Chalk rock	1600	1608	8
Shale	1608	1618	10
Rock	1618	1620	2
Gumbo	1620	1626	6
Rock	1626	1630	4
Shale	1630	1640	10
Rock	1640	1646	6
Shale	1646	1655	9
Gumbo	1655	1661	6
Rock	1661	1666	5
Shale	1666	1680	14
Rock	1680	1685	5
Gumbo	1685	1691	6
Rock	1691	1696	5
Shale	1696	1704	8
Gumbo	1704	1710	6
Rock	1710	1712	2
Gumbo	1712	1718	6
Shale	1718	1734	16
Gumbo	1734	1745	9
Rock	1745	1750	5
Shale	1750	1761	11
Gumbo	1761	1766	5
Shale	1766	1775	9
Rock	1775	1780	5
Shale	1780	1810	30
Gumbo	1810	1815	5
Hard shale	1815	1828	13

Rock	1828	1834	6
Shale	1834	1844	10
Hard sand rock, pyrites iron	1844	1855	11
White sand	1855	1862	7
Shale	1862	1868	6
Tough gumbo	1868	1876	8
Boulders	1876	1882	6
Gumbo	1882	1890	8
Gumbo and boulders	1890	1896	6
Rock	1896	1898	2
Red gumbo	1898	1906	8
Rock	1906	1908	2
Gumbo and boulders	1908	1920	12
Chalk rock	1920	1936	16
Gumbo	1936	1947	11
Hard rock	1947	1950	3
Tough red gumbo	1950	1962	12
Rock	1962	1964	2
Gumbo and boulders	1964	1990	26
Shale	1990	2000	10
Rock	2000	2010	10
Gumbo and boulders	2010	2017	7
Hard lime rock	2017	2023	6
Red gumbo	2023	2027	4
Hard rock	2027	2029	2
Sand rock, oil	2029	2031	2
Rock	2031	2032	1
Hard oil sand	2032	2035	3
Hard rock	2035	2036	1
Oil sand	2036	2038	2
Rock	2038	2039	1
Salt water sand	2039	2048	9
Rock	2048	2049	1
Slate and shale	2049	2052	3
Gumbo and boulders	2052	2054	2
Shale and boulders	2054	2062	8
Sand rock	2062	2066	4
Packed sand	2066	2070	4
Gumbo	2070	2073	3
Blue sand rock	2073	2086	13
Hard shale	2086	2096	10
Sand rock	2096	2100	4
Shale	2100	2110	10
Hard lime	2110	2137	27
Shale and boulders	2137	2151	14
Rock	2151	2153	2

Shale	2153	2170	17
Sand rock	2170	2186	16
Sandy shale, oil	2186	2196	10
Oil sand	2196	2201	5
Salt sand	2201	2202	1

No. 92.—Culberson No. 1. Elevation, 1213. Depth, 1950. A dry hole in what was considered proven territory. Plate IX, B, and XI, B.

	Feet		
	From	To	Thickness
Red	0	270	270
Oil sand	270	278	8
Shale	278	430	152
Little gas	430	445	15
Red	445	645	200
Hard lime rock	645	646-6	1′6″
Shale and broken sand	646-6	690	43′6″
Sand, show oil	690	715	25
Shale	715	730	15
Sand, good show oil	730	737	7
Red	737	770	33
Very hard rock	770	772	2
Sand	772	781	9
Red	781	840	59
Red	840	850	10
Salt water, sand	850	870	20
Red	870	977	107
Sand, gas	977	981	4
Red shale	981	992	11
Light shale	992	1001	9
Hard sand	1001	1006	5
Light shale	1006	1011	5
Very light shale	1011	1038	27
Very hard and shelly rock	1038	1043	5
Sand rock	1043	1048	5
Hard lime rock	1048	1058	10
Oil, sand	1058	1068-6	10′6″
Shale	1068-6	1080	11′6″
Salt water, sand	1080	1098	18
Shale and broken formation	1098	1352	254
Oil, sand, good show	1352	1354-6	2′6″
Shale, some broken, sand	1354-6	1405	50′6″
Shale	1405	1630	225

Sand	1630	1635	5
Shale	1635	1840	205
Shelly, little gas	1840	1848	8
Shale	1848	1870	22
Sand	1870	1871-6	1′6″
Shale, soft	1871-6	1900	28′6″
Lime rock	1900	1910	10
Black shale	1910	1920	10
White lime rock	1920	1925	5
Hard shale, broken	1925	1950	25

No. 93.—Woodruff No. 1. Whitehill and Burns. Elevation, 1173. Depth, 2035. Dry.

No. 94.—Brewer No. 2. Corsicana Petroleum Co. Elevation, 1224. Depth, 1095. Drilling commenced November 20, 1911. Drilling finished February 6, 1912. 370 feet of 12 1-2-inch casing; 775 feet of 10-inch casing; 1075 feet of 8-inch casing.

	Feet		
	From	To	Thickness
Red rock	0	100	100
Blue clay	100	140	40
Lime	140	145	5
Blue clay	145	225	80
Red rock	225	300	75
Sand	300	330	30
Blue clay	330	370	40
Lime	370	375	5
Blue clay	375	465	90
Red rock	465	525	60
Sand, gas	525	540	15
Blue clay	540	610	70
Red rock	610	650	40
Lime	650	660	10
Blue clay	660	700	40
Red rock	700	775	75
Lime	775	790	15
Blue clay	790	810	20
Red rock	810	830	20
Water, sand	830	860	30
Blue clay	860	900	40
Red rock	900	925	25
Lime	925	935	10
Blue clay	935	945	10
Red rock	945	950	5
Oil, water sand	950	977	27

Lime	977	982	5
Blue clay	982	1010	28
Red rock	1010	1050	40
Lime	1050	1060	10
Red rock	1060	1075	15
Oil, sand	1075	1095	20

No. 95.—Dale No. 1. 99 Pumping Co. Elevation, 1228. Depth, 1920.

No. 96.—Flueshe No. 1. Elevation, 1141. Depth, 2180. This well had numerous sands at approximately regular intervals, but none yielded pay.

No. 97.—Douglas No. 1. Bell and Benson. Elevation, 1234. Depth, 974.

No. 98.—Jennings No. 1. Reed & Co. This well had a good showing in the shallow sands, but drilled on in hopes of a big well deeper.

	Feet		
	From	To	Thickness
Red mud	0	10	10
Sand	10	12	2
Red clay	12	25	13
Mud	25	475	450
Shell	475	478	3
Light shale	478	528	50
Blue shale	528	628	100
Gray shale	628	633	5
Shell	633	635	2
Gray shale	635	640	5
Shell	640	644	4
Gray shale	644	674	30
Red mud	674	689	15
Gray shale	689	750	61
Lime	750	760	10
Shale, gray	760	780	20
Red mud	780	800	20
Blue slate	800	826	26
Water, sand	826	840	14
Red mud	840	875	35
Blue shale and slate	875	911	36
Oil, sand (good)	911	927	16
Red rock	927	1000	73
Blue shale and slate	1000	1035	35
Red rock	1035	1116	81

No. 99.—Honaker No. 1. Corsicana Petroleum Co. Elevation 1196. Depth, 1673.

No. 100.—Buerbaum and Culberson No. 1. Elevation, 1203. Depth, 2200. Showings were obtained in the shallow sands, but the well is not a producer.

No. 101.—Bickley No. 1. Producers Oil Co. Elevation, 1179. Depth, 870. Drilling commenced January 22, 1912. Drilling finished February 6, 1912. 34 feet of 10-inch casing; 856 feet 6 inches of 6-inch casing. Pumping 25 barrels.

		Feet	
	From	To	Thickness
Clay	0	9	9
Sand	9	16	7
Shale	16	58	42
Sand	58	64	8
Shale	64	104	40
Rock	104	105	1
Shale	105	150	45
Rock	150	154	4
Shale	154	254	100
Boulders	254	257	3
Hard shale	257	287	30
Boulders	287	293	6
Shale	293	385	92
Hard rock, oil at top	385	389	4
Shale	389	459	70
Rock	459	461	2
Hard shale	461	477	16
Rock	477	479	2
Hard shale	479	500	21
Rock	500	502	2
Hard shale	502	580	78
Hard white sand	580	585	5
Hard shale	585	600	15
Rock	600	603	3
Hard shale	603	640	37
Hard sand and oil shale	640	690	50
Rock	690	693	3
Hard shale	693	729	36
Rock	729	733	4
Hard shale	733	784	51
Rock	784	786	2
Hard shale	786	796	10
Gumbo	796	804	8

Hard shale	804	816	12
Shale	816	856	40
Oil, sand	856	870	14

No. 102.—Beat No. 1. Producers Oil Co. Elevation, 1136. This was a dry hole to a depth of 2185 feet, but is being drilled deeper.

Samples examined: 2110-2140. A white granular pure limestone, containing clear calcite in small grains, which appears porous in thin section. Part of the sample consists of structurless limestone. Some organic fragments, imperfectly shaped spines, minute bryozoa (?) or pieces of shells of foraminifera were noted.

	Feet		
	From	To	Thickness
Clay	0	50	50
Red mud	50	250	200
Sand rock	250	260	10
Red mud	260	295	35
Mixed shale	295	387	92
Blue shale	387	415	28
Red mud	415	487	72
Mixed shale	487	580	93
Sand, oil at top	580	670	90
Shale	670	700	30
Red mud	700	705	5
Red rock	705	720	15
Red mud	720	755	35
Lime shell	755	780	25
Shale	780	810	30
Red mud	810	860	50
Sand	860	870	10
Red mud	870	949	79
Lime shell	949	952	3
Red mud	952	965	13
Blue shale	965	1040	75
Red rock	1040	1070	30
Water sand	1070	1075	5
Red mud	1075	1093	18
Water sand	1093	1113	20
Red mud	1113	1164	61
Lime shell	1164	1171	7
Red mud	1171	1182	11
Sand	1182	1186	4
Blue shale	1186	1210	24
Black slate	1210	1215	5
Blue shale	1215	1245	30

Red rock	1245	1295	50
Lime shell	1295	1300	5
Red mud	1300	1303	3
Blue shale	1303	1325	22
Red mud	1325	1416	91
Water sand	1416	1436	20
Red mud	1436	1440	4
Blue shale	1440	1450	10
Water sand	1450	1460	10
Blue shale	1460	1475	15
Water sand	1475	1500	25
Blue shale	1500	1550	50
Sand	1550	1590	40
Coal formation (?)	1590	1595	5
Blue shale	1595	1617	22
Water sand	1617	1637	20
Blue shale	1637	1690	53
Lime shell	1690	1695	5
Blue shale	1695	1705	10
Lime shell	1705	1710	5
Red mud	1710	1715	5
Lime shell	1715	1720	5
Blue shale	1720	1745	25
Red mud	1745	1750	5
Blue shale	1750	1760	10
Sand	1760	1795	35
Blue shale	1795	1820	25
Sand	1820	1840	20
Blue shale	1840	1895	55
Red mud	1895	1905	10
Blue shale	1905	1950	45
Water sand	1950	1980	30
Blue shale	1980	2000	20
Lime shell	2000	2005	5
Red mud	2005	2060	55
Blue shale	2060	2115	55
Lime shell	2115	2125	10
Blue shale	2125	2130	5
Water sand	2130	2155	25
Blue shale	2155	2185	30
Lime shell	2185	....	..

No. 103.—Fisher No. 1. Flanagan & Co. This well had been drilled to a depth of 1375 feet with only a few sands and poor showings, but is being drilled deeper in hopes of a deep sand.

No. 104.—Mariott No. 1. Producers Oil Co. Elevation, 1177.

No. 105.—Honaker No. 1. Honaker Oil Co. This well had been drilled to a depth of more than 1800 feet with no pay sands, but is going deeper.

No. 106.—Hines No. 1. Fowlkes Townsite Co. No other data.

No. 107.—A well was drilled 300 feet deep about one-half mile north of Burk Station. The formations were mostly clay and shale, neither water nor oil being obtained.

No. 108.—Fort Worth & Denver Railroad well at Burk Station. In 1900 the Fort Worth & Denver Railroad bored for water near Burk Station. This boring was 280 feet deep and some oil was reported. A memory record furnished by Dr. J. M. Bell of Wichita Falls says the first 167 feet consisted of clay and red shale, under which there was 37 feet of fine hard sand, in which a trace of oil was noted. Under this was blue and red shale to 267 feet, and a coarse sand to the bottom. From this sand, several barrels of a black, heavy lubricating oil were bailed.

No. 109.—On the D. W. Ogden farm, about three miles north of Burk Station, a well some sixty feet deep yas dug over twenty years ago, securing a good supply of water. The elevation of the well is about 1065 feet above sea level. Twenty-seven feet down in this well a thin seam of coal was found, underlying sand. The bottom of the well was in blue clay.

No. 110.—Fassett No. 2. McAllister & Co. Some gas was reported from about 500 feet in this well, with showings of oil. Drilling.

No. 111.—Fassett No. 1. McAllister & Co. This well was lost before any showings had been reached. The tools were moved to No. 110.

No. 112.—Williams No. 1. Buerbaum & Co. Showings had been reported from this well, but no figures were available.

No. 113.—Roberts No. 1. Dismukes & O'Neall. This well was started with a portable machine but changed to a standard derrick and was drilling.

No. 114.—Winfrey No. 1. A good show of oil was found at 144 feet.

No. 115.—Overby No. 2. Dismukes & O'Neall. Drilling.

No. 116.—Overby No. 1. Dismukes & O'Neall. This well was lost at 570 feet and the tools moved to No. 115.

No. 117.—Iowa Park Oil & Gas Co. No. 1. This well is located in the northeast quarter of Survey 12, Tarrant County School Land, about one and three-quarters mile north-northeast from railroad station at Iowa Park, not far from east bank of the principal creek in that survey. The elevation of its curb is 1030 feet above sea level (aneroid checked to Iowa Park depot). It was completed in March, 1911. Water found at 1600 feet below the surface was briny and overflowed for a time. A sample of the last cuttings on the dump of this well consisted of blue and red shale, and fragments of white, pink, brown, and black limestone and of pyrite. A record of the strata penetrated was obtained from the secretary of the company and is as below:

	Feet		
	From	To	Thickness
Red clay	0	665	665
Sand, dry	665	680	15
Red clay	680	725	45
Dry sand, with odor of oil	725	726	1
Red clay, dry	726	975	249
Sand, salt water	975	990	15
"Red and clay"	990	1090	100
Sand, trace of oil	1090	1091	1
Red and blue clay	1091	1120	29
Sand water	1120	1130	10
Red and blue clay	1130	1210	80
Sand water	1210	1240	30
Red and blue clay	1240	1250	10
Sand, water	1250	1280	30
Red and blue clay	1280	1315	35
Sand, very hard, some gas	1315	1350	35
Blue shale	1350	1365	15
Sand, hard	1365	1380	15
Blue shale	1380	1415	35
Sand, hard	1415	1430	15
Blue shale	1430	1475	45
Sand, dry	1475	1485	10
Blue shale	1485	1500	15
Blue shale	1500	1570	70
Sand, water	1570	1605	35
Red clay	1605	1620	15
Sand water (oil show)	1620	1635	15
Blue shale	1635	1650	15

Sand, dry	1650	1665	15
Blue shale	1665	1680	15
Sand, salt water	1680	1760	80
Blue shale	1760	1770	10
Red clay	1770	1795	25
Blue shale	1795	1805	10
Red clay	1805	1820	15
Blue shale	1820	1830	10
Red clay	1830	1840	10
Blue shale	1840	1855	15
Red clay	1855	1860	5
Blue clay	1860	1865	5
Red clay	1865	1876	11

No. 118.—Atkins No. 1. Corsicana Petroleum Co. Drilling.

No. 119.—The Allendale well. This well is located on block 14 of the Denton County School Lands about six miles southwest of Wichita Falls and has an elevation of about 1000 feet above sea level. It is on the south side of the Wichita Valley Railroad. It was drilled 200 feet deep by a private company exploring for oil or gas. It yielded some gas.

The Duckett Brothers made another well, near to this well, 40 feet deep and obtained gas, which issued in quantity sufficient to be ignited a year after the well was completed.

No. 120.—Woodall No. 1. Mowris & Co. Showings were reported from about 900 feet. Drilling.

No. 121.—Marlow and Stone well at Wichita Falls. Near the center of the E. F. Austin survey about two miles west-southwest of the railroad station in Wichita Falls, Marlow and Stone completed an oil test hole in March, 1911. Most of the material penetrated was red and blue clay. There was forty feet of sand somewhere between 500 and 600 feet below the surface. This sand contained salt water near its bottom, which rose only twenty feet in the well. Some slight evidence of gas was also reported. Estimated elevation, 975 feet above sea level.

No. 122.—Bacon Siding No. 1. Thatcher & Culberson. Numerous showings of oil and gas were reported at depths less than 1400 feet, but no authoritative information could be obtained.

No. 123.—Musgrove Farm well. About in the year 1900 a well was made 280 feet deep on the Henry Musgrove farm, on the W. R. Brinley survey, about five miles north of Wichita Falls. Most of the material penetrated was red and blue shale. Salt water was obtained. Oil accumulated on the surface of the water and samples of oil were obtained occasionally for several years after the well was made. Estimated elevation, 970 feet above sea level.

No. 124.—Ice Factory Well, Wichita Falls. This well was made by a local company as a prospect, in 1892. Its depth is reported having been 840 feet. Most of the material below 25 feet was red clay. There was plenty of good water above this red clay, and "indications" of oil were reported in association with salt water from some greater depth. Elevation, 946 feet above sea level. It is located close to the union depot.

Clay County.

No. 125.—Avis No. 1. Avis Oil Co. The well is located about twelve miles west of Henrietta. Three sands showing oil were said to have been found in the first 300 feet, but no authoritative information could be secured.

No. 126.—Thornberry No. 1. Benson and Little. The well is located about eleven miles north-northeast of Wichita Falls, near Old Thornberry. Reports from the first 700 feet mention several good showings at depths approximately equal to those at Petrolia, due allowance being made for difference of elevation. It is estimated that the elevation of the Thornberry well is 930, or about fifty feet below Petrolia.

No. 127.—McGregor No. 1. Jack Kelly. This well is located about half a mile northwest of Mabledean. Several sands, none carrying oil or gas in appreciable quantities, had been reported in the first 1000 feet.

No. 128.—Holt water well. This is a shallow well, bored for water, about four miles south of Halsell in the southern part of Clay County. Sufficient oil to gum on top of the water is said to have come from 120 feet.

No. 129.—Kempner No. 1. Producers Oil Co. Elevation, 954. Depth, 2110. This well was dry, about six miles southwest of the Petrolia Gas Field.

No. 130.—Halsell Farm No. 1. Producers Oil Co. This well is located about six and one-half miles west and one hile south of Henrietta in Clay County, near the northwest corner of survey 6 of the M. Scurlock subdivision. The total depth of this well is 3985 feet, it being the deepest well yet made in this region. Drilling commenced on the first day of April, 1909. The curb of the well has an elevation of 871 feet above sea level, according to a survey made by one of the oil companies now operating in this part of the state. See page 77 and following for descriptions of samples and Fig. 8 for section. The drillers' log is as follows:

	—Depth in Feet—		
	From	To	Thickness
Red Clay	0	65	65
Salt water, sand	65	90	25
Red rock	90	190	100
Sat water, sand	190	220	30
Red Rock	220	465	245
Salt water, sand	465	505	40
Red rock	505	630	125
Salt water, sand	630	660	30
Red rock	660	772	112
Water, sand	772	797	25
Slate and red rock	797	817	20
Sand, no water	817	841	24
Red rock	842	891	99
Sand	891	911	20
Slate and red rock	911	1010	99
Dry sand	1010	1016	6
Sand	1016	1022	6
Putty	1022	1042	20
Red rock	1042	1092	50
Red mud	1092	1100	8
Water, sand	1100	1150	50
Blue mud	1150	1175	25
Red and white sand	1175	1240	65
Light blue shale	1240	1255	15
Black shale	1255	1275	20
Red shale	1275	1305	30
Brown shale	1305	1313	8
Red rock	1313	1323	10
Gray hard sand	1323	1325	2
Red and blue mud	1325	1355	30
Joint clay	1355	1365	10
Light blue shale	1365	1375	10
White sand	1375	1410	35
White slate	1410	1420	10
Gray lime	1420	1436	16
White sand	1436	1445	9
Gray lime	1445	1455	10
Dark blue slate	1455	1500	45
Red and blue mud	1500	1503	3
Rotten sand	1503	1508	5
Sky blue shale	1508	1513	5

Red cave	1513	1535	22
Dark blue shale	1535	1550	15
White sand	1550	1580	30
Dark blue shale	1580	1644	64
Gray lime, hard	1644	1655	11
Blue shale	1655	1800	44
White sand	1800	1820	20
Shale, breaks, caves	1820	1822	2
Lime shells	1822	1832	10
Gray sand, dry	1832	1837	5
Blue shale	1837	1847	10
Blue mud, caves	1847	1857	10
Light blue shale	1857	1895	38
Dry sand	1895	1905	10
Black slate	1905	1933	28
Sand, salt water	1933	1953	20
Blue marl	1953	1983	30
Gray lime	1983	2008	25
Blue marl	2008	2058	50
Black slate, gritty	2058	2125	67
Sand, artesian flow of salt water	2125	2170	45
Break	2170	2175	5
Sand	2175	2180	5
Sand	2180	2185	5
Sand	2185	2190	5
Sand	2190	2200	10
Hard brown shells	2200	2215	15
Blue shale	2215	2225	10
Sand, dark clay	2225	2280	55
Sand, dark gray, broken	2280	2300	20
Sand, light gray	2320	2335	15
Brown shale	2320	2335	15
Hard shells	2335	2350	15
Light blue slate	2350	2355	5
Brown shale	2355	2425	70
Blue slate	2425	2450	25
Brown limestone	2450	2500	50
Blue shale	2500	2600	100
Blue shale	2600	2675	75
Shells of hard sand with streaks of gray limestone	2675	2700	25
Blue shale	2700	2705	5
Lime shells and streaks of blue shale	2705	2710	5

Lime and streaks of hard sand	2710	2740	30
Light blue shale	2740	2968	228
Six feet sand, a break of 3 and3 feet solid sand	2968	2980	12
Very black shale	2980	3220	240
Limestone shells	3220	3350	130
Dark shale	3350	3382	32
Light gray sand (shows little water)	3382	3394	12
Dark slate	3394	3415	21
Sand	3415	3440	25
Dark blue shale	3440	3695	255
Dark shale	3695	3970	285
Dark gray lime	3970	3985	15
Lost tool in lime at	3985	....	...

No. 131.—Edrington No. 1. Corsicana Petroleum Co. Elevation, 1000 (estimated). Depth, 1944. This well is located about six miles southwest of the Petrolia Gas Field, and about two miles southeast of No. 129. It is reported a dry hole. Plate V.

	Feet		
	From	To	Thickness
Red mud	0	10	10
Sand rock	10	15	5
Red mud	15	65	50
Sand rock	65	75	10
Blue mud	75	125	50
Sand rock	125	145	20
Red mud	145	150	5
Sand rock	150	165	15
Red mud	165	175	10
Sand rock	175	195	20
Red mud, mixed	195	365	170
Sand rock	365	400	35
Red mud, mixed	400	420	20
Sand rock	420	430	10
Red mud, mixed	430	445	15
Sand rock	445	450	5
Red mud, mixed	450	460	10
Sand rock	460	465	5
Red mud, mixed	465	470	5
Sand rock	470	475	5
Red mud	475	485	10
Sand rock	485	490	5

Red mud, mixed.......	490	525	35
White rock............	525	550	25
Red mud, mixed.......	550	635	85
Sand rock............	635	645	10
Red mud, mixed.......	645	675	30
Sand rock............	675	680	5
Red mud.............	680	690	10
Sand rock............	690	735	45
Blue mud............	735	740	5
Sand rock............	740	760	20
Red mud.............	760	780	20
Flint rock.............	780	785	5
White mud...........	785	795	10
Sand rock............	795	840	45
Red mud, mixed.......	840	860	20
Flint rock............	860	865	5
Gypsum rock...........	865	880	15
Red mud, mixed.......	880	890	10
Sand rock............	890	902	12
Gypsum rock..........	902	912	10
Sand rock............	912	970	58
Red mud...............	970	995	25
Sand rock............	995	1000	5
Red mud, mixed.......	1000	1010	10
Gypsum rock.........	1010	1015	5
Red mud.............	1015	1040	25
Sand rock..............	1040	1078	38
Red mud.............	1078	1110	32
Sand rock............	1110	1175	65
Red mud.............	1175	1215	40
White rock...........	1215	1220	5
Red mud..............	1220	1233	13
Sand rock.............	1233	1241	8
Red mud, mixed.......	1241	1262	21
Sand rock..............	1262	1265	3
White mud, mixed......	1265	1282	17
Sand rock............	1282	1291	9
Slate rock.............	1291	1310	19
Blue shale............	1310	1325	15
Sand rock............	1325	1330	5
Blue shale............	1330	1360	30
Red mud, mixed.......	1360	1395	35
White mud...........	1395	1415	20
Sand rock..............	1415	1420	5
Red mud, mixed.......	1420	1430	10
Sand rock............	1430	1445	15
Red mud............	1445	1465	20

White rock	1465	1480	15
Blue shale	1480	1510	30
Sand rock	1510	1520	10
Blue shale	1520	1602	82
Sand rock	1602	1610	8
Gypsum rock	1610	1614	4
Red mud, mixed	1614	1621	7
Blue shale	1621	1634	13
Sand rock	1634	1645	11
Blue shale	1645	1680	35
Sand rock	1680	1692	12
Red mud, mixed	1692	1705	13
Blue shale	1705	1720	15
Blue lime	1720	1726	6
Sand rock	1726	1739	13
Blue shale	1739	1750	11
Blue lime	1750	1752	2
Blue shale	1752	1756	4
White lime	1756	1761	5
Sand rock	1761	1778	17
Red mud	1778	1802	24
Sand rock	1802	1812	10
Blue shale	1812	1828	16
Sand rock	1828	1839	11
Blue shale	1839	1885	46
Flint rock	1885	1892	7
Red mud, mixed	1892	1908	16
Flint rock	1908	1912	4
Sand rock	1912	1944	32

No. 182.—Morgan Jones No. 1. 99 Pumping Co. This well is on the western edge of the proven gas field at Petrolia. A big gas sand was met at 1685 feet, but was cased off, and the well drilled on to a depth of 1835 feet without finding a paying oil sand. Plate VII.

	Feet		
	From	To	Thickness
Clay	0	10	10
Sand	10	14	4
Yellow clay	14	42	28
Sand	42	44	2
Shale, blue	44	80	36
Sand, show oil	80	87	7
Red mud, mixed	87	140	53
Sand	140	152	12
Hard shale	152	194	42
Red mud, mixed	194	241	47

Sand rock	241	253	12
Hard shale	253	310	57
Gumbo	310	345	35
Shale	345	370	25
Sand rock	370	381	11
Red mud, mixed	381	408	27
Hard shale, dark	408	436	28
Sand rock	436	450	14
Red gumbo	450	490	40
Hard shale, light	490	520	30
Red mud, mixed	520	540	20
Blue shale	540	550	10
Sand, show oil	550	559	9
Gumbo	559	572	13
Sand, rock, water	572	630	58
Shale, blue	630	655	25
Gumbo	655	680	25
Sand rock	680	710	30
Hard light shale	710	750	40
Red mud, mixed	750	795	45
Hard shale	795	820	25
Sand rock	820	855	35
Red mud, mixed	855	895	40
Sand rock	895	930	35
Blue shale	930	956	26
Gumbo	956	960	4
Oil sand, water	960	997	37
Blue shale	997	1005	8
Slate	1005	1050	45
Sand rock	1050	1110	60
Shale, dark	1110	1143	33
Lime and gypsum	1143	1194	51
Shale, black	1194	1223	29
Lime and gypsum	1223	1340	171
Shale, hard	1340	1372	32
Sand, rock	1372	1467	95
Hard shale	1467	1480	13
Blue shale	1480	1495	15
Sand rock	1495	1536	41
Blue shale	1536	1585	49
Hard slatey shale	1585	1602	17
Dead sand	1602	1606	4
Gumbo, blue	1606	1618	12
Sand rock	1618	1631	13
Salty shale, dark	1631	1685	54
Gas, sand	1685	1686′ 6″	1′ 6″
Red shale	1686′ 6″	1690	3′ 6″

Oil sand	1690	1691	1
Hard black shale	1691	1695	4
Hard sand dead	1695	1696	1
Red black shale	1696	1727	31
Sand rock (water)	1727	1732	5
Shale, red, blue	1732	1734	2
Dead Sand	1734	1736′ 6″	2′ 6″
Oil and gas, sand	1736′ 6″	1742	5′ 6″
Slatey shale, black	1742	1753	11
Boulders	1753	1756	3
Flint rock	1756	1759	3
Gumbo	1759	1762	3
Oil and gas	1762	1768	6
Gumbo	1768	1769	1
Slatey shale, dark	1769	1775	6
Black sand	1775	1782	7
Hard shale	1782	1793	11
Dark sand	1793	1802	9
Hard dark lime	1802	1835	33

No. 133.—Byers No. 8. Producers Oil Co. Elevation, 978. Depth, incomplete, 1823. This is a gas well, also producing a small amount of oil. Plate IV.

No. 134.—Byers No. 7. Lone Star Gas Co. Elevation, 970. Depth, 1781. Building commenced Nov. 26, 1910. Drilling finished March 25, 1911. 45 feet of 10-inch casing; 1652 feet of 6-inch casing; 1768 feet of 4-inch casing. This was an edge well which produced about 25 barrels of oil and a small amount of gas when drilled in. Plate IV.

	Feet		
	From	To	Thickness
Red mud	0	50	50
Mixed mud	50	100	50
Rock sand	100	105	5
Red mud	105	175	70
Sand rock	175	185	10
Red mud	185	385	200
Sand rock	385	400	15
Mixed mud	400	500	100
Sand rock	500	525	25
Mixed mud	525	600	75
Sand rock	600	625	25
Red mud	625	700	75
Rock and mud	700	750	50
Mixed mud	750	800	50
Sand rock	800	825	25

Lead colored mud	825	900	75
Sand rock	900	905	5
Lead colored mud	905	1000	95
Sand rock	1000	1010	10
Lead colored mud	1010	1050	40
Sand rock	1050	1055	5
Mud and gypsum	1055	1100	45
Lead colored mud	1100	1125	25
Sand rock	1125	1135	10
Mud and gypsum	1135	1155	20
Mud and gypsum	1155	1190	35
Sand rock	1190	1220	30
Gypsum and lime rock	1220	1400	180
Dark shale	1400	1425	25
Rock sand, salt water	1425	1485	60
Gypsum rock	1485	1528	43
Lime rock	1528	1530	2
Dark shale	1530	1570	40
White mud	1570	1575	5
Dark shale	1575	1610	35
White mud	1610	1615	5
Dark shale	1615	1630	15
Sand rock	1630	1635	5
Dark shale	1635	1651	16
Sand rock (set 6 inch)	1651	1653	2
Dark shale	1653	1654	1
Hard sand rock	1654	1657	3
Dark shale	1657	1660	3
Sand rock	1660	1661	1
Dark shale	1661	1667	6
Lime rock	1667	1668	1
Dark shale	1668	1680	12
White mud	1680	1690	10
Flint rock	1690	1691	1
Dark shale	1691	1735	44
White mud	1735	1750	15
Red mud	1750	1755	5
Flint rock	1755	1757	2
White mud	1757	1765	8
Flint rock	1765	1766	1
Dark shale	1766	1767	1
Gas sand (set 4 inch)	1767	1776	9
White mud and hard sand	1776	1781	5

No. 135.—Byers No. 9. Producers Oil Co. This well yielded about 50 barrels of oil.

No. 136.—Byers No. 6. Lone Star Gas Co. Elevation, 970 (estimated). Depth, 1769. Drilling commenced May 26, 1910. Drilling finished Sept. 26, 1910. 1558 feet of 6-inch pipe; 1729 feet of 4-inch line pipe; 40 feet of 4-inch perforated pipe. This is a gas well. Plate IV.

	Feet		
	From	To	Thickness
Sand and clay	0	16	16
Sand rock	16	23	7
Blue shale	23	340	317
Sand rock	340	346	6
Blue shale	346	470	124
Sand rock	470	474	4
Hard shale	474	563	89
Sand rock	563	565	2
Mixed shale	565	614	49
Flint rock	614	634	20
Mixed shale	634	852	218
Sand rock	852	866	14
Hard sand	866	894	28
Sand rock	894	945	51
Hard mixed shale	945	1019	74
Sand rock	1019	1035	16
Mixed shale	1035	1261	226
Blue lime rock	1261	1271	10
Hard blue shale	1271	1326	55
Sand rock	1326	1366	40
Hard sand rock	1366	1382	16
Mixed shale	1382	1413	31
Hard shale, mixed	1413	1484	71
Soft blue shale	1484	1521	37
Mixed shale	1521	1536	15
Sand rock	1536	1537	1
Brown mud	1537	1548	11
Blue slate	1548	1553	5
Lime rock	1553	1554	1
White mud	1554	1559	5
Hard gray sand	1559	1563	4
White mud	1563	1581	18
Blue shale	1581	1596	15
White mud	1596	1607	11
Blue shale	1607	1619	12
White mud	1619	1631	12
Brown shale	1631	1636	5
White mud	1636	1671	35
Red and blue shale	1671	1676	5
Gas sand	1676	1690	14

White mud	1690	1702	12
Gas sand	1702	1719	17
Gypsum rock	1719	1739	20
Dark shale	1739	1753	14
White mud	1753	1758	5
Dark shale	1758	1766	8
White mud	1766	1768	2
Sand rock	1768	1769	1

No. 137.—**Byers No. 4. Lone Star Gas Co. Elevation, 946. Depth, 1721. Drilling commenced June 23, 1909. Drilling finished Sept. 13, 1909. 32 feet 8 inches of 10-inch casing; 1001 feet of 6-inch casing; 1531 feet of 4-inch casing; 1721 feet of 2 1-2-inch casing; 70 feet of perforated pipe in bottom of hole. A producing gas well.** Plate V.

	Feet		
	From	To	Thickness
Surface clay	0	10	10
Sand rock	10	15	5
Red mud	15	35	20
Sand rock	35	55	20
Red mud	55	70	15
Sand rock	70	80	10
Red mud	80	100	20
Sand rock	100	120	20
Red mud	120	160	40
Sand rock	160	180	20
Red mud	180	240	60
Sand rock	240	300	60
Red mud	300	350	50
Sand rock	350	375	25
Red mud	375	425	50
Sand rock	425	600	175
Red mud	600	620	20
Sand rock	620	700	80
Red mud	700	740	40
Sand rock	740	780	40
Red mud	780	790	10
Sand rock	790	800	10
Red mud	800	810	10
Blue mud	810	815	5
Red mud	815	840	25
Gypsum rock	840	880	40
Sand rock	880	900	20
Mixed mud	900	960	60
Red mud	960	980	20
Mixed mud	980	1000	20

White mud	1000	1020	20
Dark mud	1020	1120	100
Sand rock	1120	1140	20
Red mud	1140	1250	110
Water sand, last water	1250	1510	160
Dark mud	1410	1460	50
Sand rock	1460	1462	2
Red mud	1462	1495	33
Sand rock	1495	1500	5
Mud	1500	1505	5
Sand rock	1505	1507	2
Mud	1507	1520	13
Sand rock	1520	1530	10
Gray sand	1530	1531	1
Blue shale	1531	1535	4
Sand	1535	1537	2
Dark shale	1537	1584	47
Sand rock	1584	1585	1
White mud	1585	1588	3
Gray flint rock	1588	1595	7
Mixed shale	1595	1599	4
White mud	1599	1601	2
Gas sand	1601	1604	3
White mud	1604	1606	2
White sand rock, no water	1606	1615	9
White mud	1615	1617	2
Gas sand	1617	1619	2
Mixed mud	1619	1632	13
Gray sand	1632	1636	4
White mud	1636	1638	2
Gas sand	1638	1640	2
Mixed mud	1640	1642	2
White mud	1642	1648	6
Gas sand	1648	1650	2
Mixed mud	1650	1652	2
White mud	1652	1653	1
Gas sand	1653	1660	7
White mud	1660	1662	2
Mixed mud	1662	1670	8
White mud	1670	1675	5
Mixed mud	1675	1685	10
White mud	1685	1686	1
Gas sand	1686	1721	35

No. 138.—Boddy & Wantland No. 1. Lone Star Gas Co. Elevation, 958. Depth, 1902. Drilling completed Aug. 13, 1910. This

is a dry hole on the northern edge of the producing gas field at Petrolia. Plate IV.

		Feet	
	From	To	Thickness
Sod	0	1	1
Red clay	1	15	14
Water sand	15	25	10
Red clay and gravel	25	85	60
Sand	85	88	3
Red clay and gravel	88	133	45
Broken sand	135	163	30
Red clay and gravel	163	213	50
Hard sand rock	213	219	6
Red mud and gravel	219	249	30
Brown clay	249	257	8
Red tough mud	257	287	30
Mud and gravel	287	349	62
Red shale	349	399	50
Broken sand	399	414	15
Red mud	414	519	105
Water sand	519	529	10
Red mud	529	569	40
Red shale	569	694	125
Red mud and gravel	694	714	20
Broken sand	714	724	10
Brown clay	724	754	30
Iron pyrite	754	762	8
Loose gravel	762	767	5
Red mud and gravel	767	842	75
Red tough mud	842	872	30
Mud and gravel	872	927	55
Blue and red mud	927	939	12
Red mud and gravel	939	1002	63
Blue mud and boulders	1002	1007	5
Water sand	1007	1013	6
Red mud and gravel	1013	1040	27
Blue gumbo	1040	1050	10
Red mud and gravel	1050	1092	42
Blue gumbo	1092	1112	20
Hard sand rock	1112	1120	8
Blue gumbo and boulders	1120	1140	20
Black slate and sand	1140	1180	40
Red mud and gravel	1180	1208	28
Blue and red gravel	1208	1230	22
Blue gumbo	1230	1235	5

Sand boulders........	1235	1239	4
Hard sand rock.......	1239	1245	6
Broken sand.........	1245	1252	7
Blue gumbo and boulders	1252	1275	23
Blue sand and slate...	1275	1295	20
Blue gumbo and boulders	1295	1310	15
Water sand..........	1310	1328	18
Hard sand...........	1328	1330	2
Blue gumbo and boulders	1330	1335	5
Hard sand rock.......	1335	1339	4
Blue gumbo and boulders	1339	1345	6
Quartz	1345	1348	3
Blue gumbo and boulders	1348	1358	10
Hard black sand rock..	1358	1364	6
Water sand..........	1364	1375	11
Blue gumbo and boulders	1375	1395	20
Quartz	1395	1399	4
Blue gumbo..........	1399	1411	12
Blue and red shale....	1411	1471	60
Hard sand rock.......	1471	1473	2
Soft sand rock........	1473	1477	4
Blue gumbo..........	1477	1479	2
Hard sand...........	1479	1487	8
Water sand..........	1487	1492	5
Blue gumbo..........	1492	1500	8
Blue gumbo and boulders	1500	1506	6
Sand rock...........	1506	1511	5
White talc (?).......	1511	1514	3
Broken sand.........	1514	1521	7
Water sand..........	1521	1527	6
Blue hard slate.......	1527	1543	16
White talc (?).......	1543	1547	4
Blue hard slate.......	1547	1559	12
White talc (?).......	1559	1565	6
Broken sand and slate.	1565	1577	12
Blue shale...........	1577	1595	18
Hard shell...........	1595	1596	1
White talc...........	1596	1600	4
Blue gumbo..........	1600	1657	57
Blue shale......... .	1657	1665	8

Blue gumbo	1665	1686	21
Blue gumbo and boulders	1686	1713	26
Black shale and sand	1713	1721	8
Blue shale	1721	1751	30
Blue gumbo	1751	1768	17
Black slate	1768	1786	18
Blue gumbo	1786	1817	31
Blue sand rock	1817	1818	1
Blue gumbo	1818	1881	63
Black slate	1881	1891	10
Blue gumbo	1891	1902	11

No. 139.—Byers No. 5. Lone Star Gas Co. Elevation, 981. Depth, 1643. Drilling commenced Dec. 4, 1909. Drilling finished Feb. 25, 1910. 96 feet 5 inches of 10-inch casing; 1468 feet of 6-inch casing; 1567 feet of 4-inch casing. Plate IV.

	Feet		
	From	To	Thickness
Red mud	0	20	20
White rock	20	21	1
Red mud	21	81	60
Mixed mud	81	200	119
White rock	200	205	5
Mixed mud	205	400	195
White rock	400	420	20
Mixed mud	420	600	180
White rock	600	630	30
Mixed mud	630	800	170
White rock	800	810	10
Mud, lead color	810	850	40
Gypsum rock	850	900	50
Mud, lead color	900	970	70
White sand rock	970	1000	30
Mud, lead color	1000	1020	20
Gypsum rock	1020	1070	50
White sand rock	1070	1100	30
Gypsum rock	1100	1130	30
Sand rock	1130	1150	20
Mud, lead color	1150	1160	10
Gypsum rock	1160	1175	15
Sand rock	1175	1210	35
Brown shale	1210	1260	50
Sand rock	1260	1300	40
Brown shale	1300	1397	97
Sand rock	1397	1399	2

Brown shale	1399	1431	32
Sand rock	1431	1432	1
Brown shale	1432	1466	34
Sand rock	1466	1470	4
Brown shale	1470	1563	93
Flint rock	1563	1565	2
White mud	1565	1566	1
Sand rock, gas sand	1566	1568	2
White mud	1568	1572	4
Gas sand	1572	1595	23
Sand rock, hard	1595	1598	3
Brown shale	1598	1600	2
Sand rock	1600	1601	1
White mud	1601	1605	4
Sand rock, hard	1605	1607	2
Brown shale	1607	1612	5
Gas sand	1612	1621	9
White mud	1621	1624	3
Brown shale	1624	1643	19

No. 140.—Blattner No. 1. No data obtained.

No. 141.—Byers No. 2. Producers Oil Co. Elevation, 1010 (estimated). Depth, 2135. This is a dry hole, located about four miles north of the Petrolia gas field.

No. 142.—Byers Block 67. Depth, 1300. This well is about two miles northeast of Petrolia. Little information could be obtained, other than that it produced gas.

No. 143.—Byers No. 1. Lone Star Gas Co. Elevation, 960 (estimated). Depth, 1736. Drilling commenced May 7, 1907. Drilling finished April, 1909. 567 feet of 10-inch line pipe; 1278 feet of 8-inch line pipe; 1598 feet of 6-inch drive pipe; 1683 feet of 4 1-2-inch drive pipe; packer set at 1736 feet; 6-in casing followed through upper gas sand to 1602 feet; 4 1-2-inch casing followed through second gas sand to 1683 feet. Plate VII.

	Feet		
	From	To	Thickness
Red surface clay	0	20	20
Water sand	20	40	20
Red rock	40	230	190
Water sand	230	245	15
Blue shale	245	270	25
Water sand	270	285	15
Red rock	285	350	65

Water sand..........	350	359	9
Red and blue mud....	359	392	33
Water sand..........	392	402	10
Red rock............	402	412	10
Dry sand............	412	417	5
Blue and red mud....	417	500	83
Soapstone and red rock	500	530	30
Red rock............	530	580	50
Sand rock, dry.......	580	583	3
Red rock............	583	660	77
Light shale..........	660	715	55
Gray sand...........	715	730	15
Blue shale...........	730	750	20
Red rock and gravel...	750	785	35
Blue shale...........	785	820	35
White lime..........	820	825	5
Blue shale...........	825	853	28
Gray sand...........	853	870	17
Blue shale...........	870	885	15
Red mud............	885	895	10
White lime	910	913	3
Missing	895	910	13
White sand..........	913	931	18
Blue shale...........	931	936	5
White sand..........	936	975	39
Stratified red and blue.	975	995	20
Blue shale...........	995	1000	5
Blue shale...........	1000	1005	5
White shale.........	1005	1015	10
Red mud............	1015	1020	5
White sand..........	1020	1040	20
Blue shale...........	1040	1045	5
Dark gray sand.......	1045	1050	5
Brown shale.........	1050	1070	20
Blue shale...........	1070	1110	40
Red mud............	1110	1130	20
Blue shale...........	1130	1206	76
Blue and gray shale...	1206	1235	29
Blue sand...........	1235	1240	5
Blue shale...........	1240	1260	20
Black sand..........	1260	1266	6
Black shale..........	1266	1300	34
Sand	1300	1305	5
Black shale..........	1305	1320	15
Sand	1320	1328	8
Black shale..........	1328	1333	5
Sand	1333	1338	5

Black shale	1338	1413	75
Blue sand	1413	1428	15
Black shale	1428	1433	5
Sand	1433	1438	5
Shale	1438	1443	5
Sand	1443	1448	5
Black sand	1448	1453	5
Shale	1453	1461	8
Black sand	1461	1464	3
White sand	1464	1490	26
Black shale	1490	1495	5
Black sand	1495	1515	20
Blue mud or shale	1515	1518	3
Sand and shale	1518	1519	1
Blue shale	1519	1598	79
Gas sand	1598	1600	2
Brown shale	1600	1608	8
Oil sand (slight showing)	1608	1610	2
Blue shale	1610	1670	60
Dry sand (top containing 2nd gas strata)	1670	1686	16
Blue shale	1686	1723	37
Dry gray sand	1723	1727	4
Blue shale	1727	1731	4
Gas sand (top very hard)	1731	1736	5

No. 144.—Stine No. 1, Block 13. Lone Star Gas Co. Elevation, 931. Depth, 1726. Drilling completed Sept. 21, 1909. 21 feet 6 inches of 10-inch casing; 930 feet of 6-inch casing; 1426 feet of 4-inch casing; 1726 feet of 2-inch casing. Plate V.

	Feet		
	From	To	Thickness
Surface	0	21	21
Sand rock	21	23	2
Red formation	23	65	42
Sand rock	65	68	3
Red formation	68	130	62
Sand, "showing of oil"	130	134	4
Red formation	134	260	126
Sand, "good show of oil"	260	275	15
Red formation	275	490	215
Hard sand rock	490	501	11
Red formation	501	930	429

Red formation........	930	1185	255
Sand	1185	1214	29
Shale	1214	1280	66
Sand, "good show of oil"	1280	1295	15
Red formation........	1295	1376	81
Sand rock...........	1376	1380	4
Black shale..........	1380	1426	46
Sand rock...........	1426	1431	5
Black shale..........	1431	1498	67
Sand rock...........	1498	1500	2
Light shale..........	1500	1517	17
Black shale..........	1517	1576	59
Sand and shale, mixed	1576	1596	20
Shale	1596	1617	21
Sand rock...........	1617	1622	5
Light shale..........	1622	1646	24
Sand, gas and oil.....	1646	1656	10
Sand and shale.......	1656	1675	19
Shale	1675	1726	51

No. 145.—Stine No. 1, Block 24. Lone Star Gas Co. Elevation, 919. Depth, 1576. Drilling commenced Feb. 22, 1909. Drilling completed April 14, 1909. 37 feet 7 inches of 10-inch casing; 999 feet 9 inches of 6-inch casing; 1414 feet of 4-inch casing. Plate V.

	Feet		
	From	To	Thickness
Red mud............	0	40	40
Rock, white sand.....	40	42	2
Red mud............	42	70	28
Rock, white sand.....	70	78	8
Red mud............	78	130	52
Rock, white sand.....	130	132	2
Mud mixed..........	132	230	98
Rock, white sand.....	230	232	2
Mud mixed..........	232	376	144
Rock, white sand.....	376	381	5
Red mud............	381	420	39
Lead color mud.......	420	445	25
Rock, pyrites of iron..	445	446	1
Rock, sand..........	446	450	4
Mixed lead (color?)...	450	460	10
Rock, white, sand.....	550	570	10
Rock, white gypsum...	570	630	60
Oil sand.............	630	634	4
Rock, white sand.....	634	640	6

Mud, blue	640	649	9
Rock, white, sand	649	651	2
Mud, white	651	670	19
Rock, white, sand	670	710	40
Rock, white, sand, hard	710	715	5
Rock, white sand, salt	715	720	5
Mud, white	720	740	20
Rock, white sand	740	750	10
Mud, blue	750	770	20
Rock white sand	770	850	80
Mud, blue	850	895	45
Rock, white, sand	895	930	35
Mud, blue	930	940	10
Rock, flint	940	995	55
Mud, dark, nearly black	995	1005	10
Rock, white sand	1005	1010	5
Mud, dark	1010	1020	10
Rock, white sand	1020	1025	5
Mud, dark	1025	1030	5
Rock, white sand	1030	1035	5
Rock, white sand, hard	1035	1040	5
Mud, dark	1040	1085	45
Rock, white sand	1085	1090	5
Mud, white	1090	1110	20
Rock, white sand	1110	1115	5
Mud, white	1115	1120	5
Rock, white sand	1120	1130	10
Mud, white	1130	1200	70
Rock, white sand	1200	1235	35
Shale, black	1235	1255	20
Mud, lead color	1255	1300	45
Mud, white	1300	1360	60
Rock, white sand	1360	1365	5
Mud, lead color	1365	1370	5
Rock, white sand	1370	1372	2
Mud, lead color	1372	1377	5
Rock, white sand	1377	1380	3
Shale, black	1380	1416	36
Rock, white sand	1416	1419	3
Mud, mixed	1419	1423	4
Rock, white sand	1423	1424	1
Shale, black	1424	1440	16
Rock, white sand	1440	1442	2
Shale, black	1442	1445	3
Rock, white sand	1445	1447	2
Shale, black	1447	1499	52

Rock, black and yellow, flint	1499	1500	1
Shale, black	1500	1507	7
Rock, flint, white	1507	1508	1
Shale, black	1508	1515	7
Rock, white sand	1515	1517	2
Shale, black	1517	1523	6
Rock, white flint	1523	1524	1
Shale, black	1524	1530	6
Mud, white	1530	1534	4
Rock, white sand	1534	1535	1
Shale, black	1535	1550	15
Rock, white sand	1550	1551	1
Mud, white	1551	1552	1
Rock, white sand	1552	1554	2
Mixed, red	1554	1570	16
Mixed	1570	1572	2
Gas sand	1572	1576	4

No. 146.—Morgan No. 1. Elevation, 960 (estimated). Depth, 388. This is one of the several hundred shallow wells in the Petrolia field, each pumping from two to five barrels a day.

		Feet	
	From	To	Thickness
Red clay	0	25	25
Fresh water sand	25	58	33
Red	58	218	160
Dry sand	218	219	1
Red	219	255	36
Sand, oil and salt water	255	269	14
Light blue and red	269	334	65
Sand, salt water	334	344	10
Blue shale	344	366	22
Red and blue shale	366	388	22

No. 147.—Morgan No. 2. Elevation as in preceding well. Depth, 266. See note on No. 146.

		Feet	
	From	To	Thickness
Red clay	0	4	4
Hard sand rock	4	9	5
Red and boulders	9	26	17
Sand dry	26	28	2
Red	28	35	7
Sand, dry	35	37	2

Red and light	37	75	38
Sand, fresh water	75	89	14
Red and light	89	248	159
Blue	248	259	11
Sand, oil and water	259	266	7

No. 148.—Lochridge No. 1. This was the first gas well drilled in this field and is still a producer. No detailed information could be secured.

No. 149.—Lochridge Farm No. 2. Lone Star Gas Co. Elevation, 940 (estimated). Depth, 1485. Drilling finished 1909. 415 feet of 10-inch casing; 995 feet of 8-inch casing; 1463 feet of 6-inch casing. Plates IV and V.

	Feet		
	From	To	Thickness
Red rock	0	195	195
Sand	195	207	12
Red rock	207	222	15
Sand	222	247	25
Blue shale	247	252	5
Oil sand	252	287	35
Red rock	287	400	113
Water sand	400	420	20
Blue shale	420	425	5
Sand	425	495	70
Blue shale	495	505	10
Water sand	505	525	20
Red rock	525	595	70
Sand	595	610	15
Red rock	610	640	30
Blue shale	640	645	5
Sand (oil and water)	645	675	30
Blue shale	675	690	15
Sand	690	700	10
Blue shale	700	720	20
Sand (oil and water)	720	735	15
Blue shale	735	740	5
Sand (oil and water)	740	760	20
Blue shale	760	780	20
Water sand	780	800	20
Brown shale	800	900	100
Red rock	900	965	65
Blue shale	965	975	10
Water sand	975	995	20
Brown shale	995	1090	95

Blue shale...........	1090	1100	10
Sand	1100	1155	55
Blue shale...........	1155	1165	10
Sand	1165	1200	35
Black shale..........	1200	1280	80
Blue shale...........	1280	1285	5
Sand	1285	1300	15
Blue shale...........	1300	1305	5
Sand	1305	1315	10
Blue shale...........	1315	1463	148
Gas sand............	1463	1473	10
Red rock............	1473	1485	12
Gas sand............	1485	....	..

No. 150.—Avis & Smith No. 1. Corsicana Petroleum Co. Depth, 783. This was a dry hole practically in the middle of the proven field.

	———	Feet	———
	From	To	Thickness
Red mud............	0	18	18
Sand, white..........	18	20	2
Rock	20	25	5
Red rock............	25	50	25
Rock, white..........	50	65	15
Mud, mixed (red, white and blue).........	65	120	55
Rock	120	121	1
Red rock............	121	190	69
Rock grey...........	190	240	50
Oil sand.............	240	245	5
Rock, gray..........	245	280	35
Mud, red and blue....	280	360	80
Rock, gray..........	360	400	40
Mud, blue...........	400	420	20
Rock, gray...........	420	435	15
Sand, white..........	435	440	5
Rock, gray..........	440	535	95
Mud, blue and red....	535	575	40
Rock, gray...........	575	585	10
Oil sand.............	585	588	3
Mud, blue...........	588	620	32
Oil sand.............	620	624	4
Rock, gray..........	624	626	2
Mud, blue and red....	626	675	49
Rock, gray...........	675	678	3
Rock, gray (soft, salt water)	678	683	5

Rock, gray (hard)....	683	685	2
Mud, white..........	685	689	13
Rock, blue...........	698	706	8
Mud, white..........	706	711	5
Rock, white..........	711	712	1
Mud, all kinds........	712	726	14
Rock, blue...........	726	727	1
Mud, white..........	727	729	2
Oil sand (tested, no good)	729	734	5
Mud, blue...........	734	740	6
Sand, white..........	740	741	1
Mud, blue...........	741	770	29
Rock, white..........	770	772	2
Sand, white (salt water)	772	783	11

No. 151.—Avis & Smith No. 2. Corsicana Petroleum Co. Elevation, 929. Depth, 1523. Drilling commenced Oct. 12, 1908. Drilling finished Feb. 9, 1909. 47 feet 8 inches of 10-inch casing; 896 feet 9 inches of 8-inch casing; 1246 feet 7 inches of 6-inch casing; 1459 feet 11 inches of 4-inch casing; 1522 feet 11 inches of 2 1-2-inch casing.

	Feet		
	From	To	Thickness
Red mud............	0	7	7
Rock, white..........	7	27	20
Red mud............	27	45	18
Rock, white..........	45	50	5
Red mud............	50	100	50
Oil sand.............	100	105	5
Rock, white..........	105	125	20
Red mud............	125	150	25
Rock, white..........	150	160	10
Oil sand.............	160	165	5
Rock, white..........	165	169	4
Mud, blue...........	169	189	20
Oil sand.............	189	196	7
Rock, white..........	196	200	4
Mud, blue............	200	220	20
Rock, white..........	220	230	10
Mud, blue...........	230	260	30
Oil sand.............	260	265	5
Rock, white..........	265	270	5
Mud, blue	270	285	15
Rock, white..........	285	350	65
Oil sand.............	350	355	5

Rock, white..........	355	385	30
Mud, blue...........	385	395	10
Rock, white..........	395	495	100
Oil sand.............	495	500	5
Rock, white..........	500	520	20
Mud, blue...........	520	550	30
Rock, white..........	550	555	5
Mud, blue...........	555	580	25
Rock, white..........	580	605	25
Oil sand.............	605	610	5
Rock, white (hard)....	610	612	2
Rock white (soft)....	612	615	3
Mud, blue...........	615	620	5
Rock, white..........	620	640	20
Mud, blue...........	640	655	15
Oil sand.............	655	660	5
Mud, blue...........	660	664	4
Rock, white..........	664	674	10
Oil sand.............	674	677	3
Mud, blue...........	677	687	10
Shale, blue..........	687	720	33
Oil sand.............	720	724	4
Rock, white..........	724	770	46
Shale, red............	770	772	2
Rock, white..........	772	784	12
Mud, blue...........	784	850	66
Rock, white..........	850	875	25
Mud, blue...........	875	900	25
Rock, white..........	900	910	10
Mud, blue............	910	925	15
Rock, white..........	925	940	15
Mud, blue............	940	950	10
Rock, white..........	950	998	48
Rock, white..........	998	1000	2
Rock flint...........	1000	1025	25
Shale, blue..........	1025	1035	10
Rock, white..........	1035	1040	5
Shale, blue..........	1040	1060	20
Rock flint...........	1060	1075	15
Rock, sand...........	1075	1080	5
Rock sand (hard)....	1080	1082	2
Rock flint and shell..	1082	1105	23
Shale, blue..........	1105	1120	15
Rock flint...........	1120	1125	5
Rock sand...........	1125	1127	2
Rock, white, flint.....	1127	1145	18
Rock sand...........	1145	1147	2

Oil sand	1147	1150	3
Rock sand	1150	1175	25
Rock sand	1175	1210	35
Rock sand	1210	1212	2
Rock sand	1212	1260	48
Mud, light	1260	1285	25
Rock sand	1285	1300	15
Mud, light	1300	1315	15
Rock sand	1315	1330	15
Mud, light blue	1330	1359	29
Rock sand	1359	1360	1
Mud, blue	1360	1366	6
Rock sand	1366	1380	14
Shale, black	1380	1438	58
Rock, white	1438	1439	1
Shale, black	1439	1459	20
Rock sand, white	1459	1460	1
Shale, black	1460	1463	3
Rock sand	1463	1465	2
Shale, black	1465	1477	12
Rock sand (soft)	1477	1487	10
Shale, blue	1487	1495	8
Shale, red	1495	1500	5
Rock sand	1500	1502	2
Rock, white (gypsum)	1502	1510	8
Shale, blue	1510	1521	11
Gas, sand, white	1521	1523	2

No. 152.—Panhandle No. 1. Lone Star Gas Co. Elevation, 924. Depth, 1592. Sand and rock, 1 to 1506. Gas sand, 1506 to 1511. Shale, 1511 to 1580. Gas sand, 1580 to 1592.

No. 153.—Panhandle Oil Co. No data other than the location was obtained regarding this well.

No. 154.—Wichita Falls Oil and Gas Co. No. 2. This is a gas well, regarding which no information was obtained.

No. 155.—Reed Winfrey No. 7. Elevation, 940 (estimated). Depth, 425. This is a shallow well similar to No. 146.

	Feet		
	From	To	Thickness
Surface	0	100	100
Red mud	100	200	100
Rock	200	250	50
Blue shale	250	266	16

Oil sand	266	288	22
Rock and clay	288	300	12
Slate	300	320	20
Blue shale	320	341	21
Oil sand	341	354	13
Rock and shale	354	400	46
Blue shale	400	416	16
Oil sand	416	425	9

No. 156.—Reed Winfrey No. 9. Elevation as in No. 155. Depth, 422. See No. 155.

	Feet		
	From	To	Thickness
Surface	0	100	100
Red mud	100	150	50
Red mud and sand	150	200	50
Stone, slate	200	250	50
Shale and slate	250	266	16
Oil sand	266	288	22
Rock and shale	288	342	54
Oil sand	342	352	10
Red shale and rock	352	385	33
Rock and shale	385	416	31
Broken oil sand	416	422	6

No. 157.—Lochridge No. 4. Clayco Oil & Pipe Line Co. Elevation, 940 (estimated). Depth, 654. This is producing from a deeper sand than Nos. 155 and 156, but is spoken of as a shallow well.

	Feet		
	From	To	Thickness
Turf	0	10	10
Red mud	10	199	189
Oil sand, gray	199	204	5
Red mud	204	231	27
Blue mud	231	241	10
Oil sand	241	261	20
Blue mud	261	265	4
Oil sand	265	275	10
Red mud	275	390	115
Blue mud	390	400	10
Sand, water	400	425	25
Blue shale	425	465	40
Sand, water	465	485	20
Blue shale	485	498	13
Sand, water	498	518	20
Blue slate	518	528	10

Red mud	528	645	117
Gray sand	645	647	2
Blue shale	647	651	4
Oil sand	651	654	3

No. 158.—Lochridge No. 2, Lease No. 2. Clayco Oil & Pipe Line Co. Elevation, 940. Depth, 750. This is producing from a still deeper sand than Nos. 155 or 157.

	Feet		
	From	To	Thickness
Red rock	0	240	240
Oil sand	240	260	20
Blue shale	260	270	10
Sand	270	290	20
Red rock	290	360	70
Black shale	360	370	10
Sand	370	400	30
Red rock	400	430	30
Sand	430	460	30
Blue shale	460	475	15
Sand	475	505	30
Red rock	505	635	130
Blue shale	635	640	5
Oil sand	640	650	10
Water sand	650	670	20
Red rock	670	700	30
Blue shale	700	710	10
White shale	710	720	10
Oil sand	720	750	30

No. 159.—Lochridge No. 3, Lease No. 2. Clayco Oil & Pipe Line Co. Elevation, 940. Depth, 744. See No. 158.

	Feet		
	From	To	Thickness
Red rock	0	250	250
Blue shale	250	260	10
Gray sand	260	272	12
Red rock	272	350	78
Blue shale	350	360	10
Gray sand	360	380	20
Red rock	380	400	20
Blue shale	400	412	12
White sand	412	432	20
Red rock	432	510	78
Blue shale	510	530	20

White sand..........	530	542	12
Red rock............	542	610	68
Blue shale..........	610	690	80
White sand..........	690	700	10
Red rock............	700	710	10
Blue shale..........	710	722	12
Oil sand............	722	733	11

No. 160.—Perkins No. 2. Clayco Oil & Pipe Line Co. Elevation, 940. Depth, 649.

	Feet		
	From	To	Thickness
Red rock............	0	190	190
Blue clay...........	190	195	5
Sand	195	205	10
Red rock............	205	250	45
Blue clay...........	250	255	5
Sand	255	270	15
Red rock............	270	340	70
Blue clay...........	340	350	10
Sand	350	370	20
Red rock............	370	385	15
Blue clay...........	385	390	5
Sand	390	425	35
Blue shale..........	425	465	40
Blue clay...........	465	480	15
Sand	480	515	35
Red rock............	515	565	50
Blue clay...........	565	575	10
Sand	575	585	10
Red rock............	585	595	10
Shell	595	600	5
Red rock............	600	610	10
Shale	610	615	5
Blue shale..........	615	620	5
Shell	620	625	5
Red rock............	625	635	10
Blue shale..........	635	644	9
Sand, oil............	644	649	5

No. 161.—Perkins No. 1. Clayco Oil & Pipe Line Co. Elevation, 940 (estimated). Depth, 724.

	Feet		
	From	To	Thickness
Red rock............	0	190	190
Blue clay...........	190	195	5
Sand	195	205	10

Red rock	205	250	45
Blue clay	250	255	5
Sand	255	270	15
Red rock	270	340	70
Blue clay	340	350	10
Sand	350	370	20
Red rock	370	385	15
Blue clay	385	390	5
Sand	390	425	35
Blue shale	425	465	40
Blue clay	465	480	15
Sand	480	515	35
Red rock	515	565	50
Blue clay	565	575	10
Sand	575	585	10
Red rock	585	595	10
Shell	595	600	5
Red rock	600	610	10
Shell	610	615	5
Blue shale	615	620	5
Shell	620	625	5
Red rock	625	635	10
Blue shale	635	644	9
Sand	644	654	10
Red rock	654	656	2
Sand	656	681	25
Blue shale	681	691	10
Sand	691	700	9
Blue shale	700	720	20
Sand	720	724	4

No. 162.—Perkins No. 3. Clayco Oil and Pipe Line Co. Elevation, 940 (estimated). Depth, 725.

	Feet		
	From	To	Thickness
Red mud	0	190	190
Gray sand	190	195	5
Red shale	195	215	20
Gray sand	215	225	10
Red shale	225	255	30
Blue shale	255	265	10
Gray sand	265	280	15
Red shale	280	345	65
Blue shale	345	350	5
Gray sand	350	365	15
Red shale	365	380	15

Blue shale...........	380	385	5
Gray sand...........	385	400	15
Blue shale...........	400	415	15
White sand..........	415	440	25
Blue shale...........	440	450	10
White sand..........	450	470	20
Blue shale...........	470	500	30
White sand..........	500	510	10
Blue shale...........	510	520	10
Red shale............	520	557	37
Blue shale...........	557	567	10
White sand..........	567	580	13
Blue shale...........	580	658	78
White sand..........	658	675	17
Blue shale...........	675	685	10
Sand	685	695	10
Blue shale...........	695	715	20
Sand	715	725-6	10-6

No. 163.—Perkins No. 4. Clayco Oil & Pipe Line Co. Elevation, 940 (estimated). Depth, 730.

	Feet		
	From	To	Thickness
Red rock............	0	190	190
Gray sand...........	190	195	5
Red rock............	195	215	20
Gray sand...........	215	225	10
Red rock............	225	255	30
Blue shale...........	255	265	10
Gray sand...........	265	280	15
Red rock............	280	345	65
Blue shale...........	345	350	5
Gray sand...........	350	365	15
Red rock............	365	380	15
Blue shale...........	380	385	5
Gray sand...........	385	400	15
Blue shale...........	400	415	15
White sand..........	415	440	25
Blue shale...........	440	450	10
White sand..........	450	470	20
Blue shale...........	470	500	30
White sand..........	500	515	15
Blue shale...........	515	520	5
Red rock............	520	560	40
Blue shale...........	560	570	10
Gray sand...........	570	575	5
Red rock............	575	635	60

Blue shale	635	645	10
Gray sand oil	645	655	10
Gray sand water	655	675	20
Blue shale	675	685	10
Shelly sand	685	695	10
Blue shale	695	715	20
Sand oil	715	730	15

No. 164.—Carrow No. 1. Clayco Oil & Pipe Line Co. Elevation, 935 (estimated). Depth, 653.

	Feet		
	From	To	Thickness
Red and gray clay	0	190	190
Oil sand	190	195	5
Red clay	195	217	22
Oil sand	217	224	7
Red clay	224	236	12
Oil sand	236	247	11
Blue shale	247	260	13
Red clay	260	295	35
Gray shale	295	343	48
Oil sand	343	365	22
Gray shale	365	392	27
Oil sand	392	398	6
Blue shale	398	405	7
Water sand	405	430	25
Gray clay	430	465	35
Blue clay	465	504	39
Water sand	504	512	8
Red clay	512	551	39
Oil sand	551	560	9
Blue clay	560	571	11
Oil sand	571	578	7
Red clay	578	609	31
Blue clay	609	649	40
Water sand	649	653	4

No. 165.—Holt Farm No. 1. Lone Star Gas Co. Elevation, 939. Depth, 1571. Drilling commenced Oct. 14, 1909. Drilling finished Dec. 13, 1909. Plate V.

	Feet		
	From	To	Thickness
Surface	0	70-6	70-6
Sandy rock and red formation	70-6	746	675-6
Sandy, light show of oil	746	752	6
Sand, salt water	752	765	13

Red formation	765	917	152
Very hard rock	917	922	5
Soft rock	922	933	11
Sand rock and red formation	933	1252	319
Hard sand, salt water	1252	1417	165
Shale	1417	1554	137
Hard cap rock	1554	1556-3	2′3″
Shale, some shells	1556-3	1564	7′9″
Gas sand	1564	1571-6	7′6″

No. 166.—Beatty. Sun Co. No information other than the location of this dry hole could be obtained.

No. 167.—Wichita Falls Oil & Gas Co. No. 2. This is a producing gas well. No other information could be procured.

No. 168.—Buckley, Brock & Lunday No. 8. Elevation, 910 (estimated). Depth, 332.

	Feet		
	From	To	Thickness
Soil and sand	0	17	17
Sand and gravel	17	20	3
Red clay	20	60	40
Light gray	60	71	11
Red clay	71	80	9
Light	80	90	10
Red	90	130	40
Light	130	141	11
Red	141	171	30
Sand	171	179	8
Red	179	204	25
Light	204	222	18
Sand, oil	222	243	21
Red	243	270	27
Light	270	290	20
Sand, water	290	298	8
Red	298	315	17
Blue	315	324	9
Sand, oil	324	332	8
Red	332		

No. 169.—Buckley, Brock and Lunday No. 9. Elevation, 910 (estimated). Depth, 332.

	Feet		
	From	To	Thickness
Soil and sand	0	20	20
Sand, water	20	26	6

Light, some blue......	26	78	52
Red clay...............	78	85	7
Light	85	92	7
Red	92	138	46
Sand	138	140	2
Red	140	160	20
Light	160	175	15
Red	175	221	46
Sand	221	246	25
Light	246	275	29
Red	275	291	16
Sand	291	304	13
Red	304	309	5
Shale	309	319	10
Sand	319	332	13
Red	332	...	..

No. 170.—Smith & Webber No. 1. Lone Star Gas Co. Elevation, 928. Depth, 1583. Drilling commenced July 14, 1909. Drilling finished November 10, 1909. 10 feet of 10-inch casing; 1430 feet of 6-inch casing; 1470 feet of 4-inch casing. Plate IV.

		Feet	
	From	To	Thickness
Red clay...............	0	4	4
Sand rock............	4	20	16
Red mud.............	20	40	20
Dark red rock........	40	360	320
Sand (slight show of oil)	360	365	5
Red rock.............	365	390	25
Sand rock............	390	678	288
Red mud and sand shells	678	700	22
Hard blue shale.......	700	765	65
Sand rock............	765	800	35
Blue shale, dark......	800	815	15
Hard sand rock........	815	840	25
Red rock.............	840	900	60
Sand rock............	900	1050	150
Red and blue clay.....	1050	1145	95
Hard gray sand (show of oil and gas)......	1145	1170	25
Hard blue shale.......	1170	1200	30
Hard rock............	1200	1235	35
Blue shale............	1235	1245	10
Sand rock.............	1245	1308	63
Red rock..............	1308	1347	39

Water, sand, rock	1347	1365	18
Blue shale	1365	1370	5
Sand, rock	1370	1400	30
Hard blue shale	1400	1415	15
Black shale	1415	1440	25
Hard dry sand, rock	1440	1444	4
Dark blue shale	1444	1575	131
Rock	1575	1576	1
Gas, sand	1576	1583	7

No. 171.—Wichita Oil Co. No. 1. This is a gas well, regarding which no information was secured.

No. 172.—Joyce No. 6. Clayco Oil & Pipe Line Co. Elevation, 930 (estimated). Depth, 386.

		Feet	
	From	To	Thickness
Clay	0	15	15
Water, sand	15	41	26
Clay	41	98	57
Oil, sand	98	110	12
Clay	110	247	137
Shale and sand	247	255	8
Clay	255	343	88
Sand	343	350	7
Clay	350	375	25
Shale	375	384	9
Salt water	384	386	2

No. 173.—Joyce No. 7. Clayco Oil & Pipe Line Co. Elevation, 930 (estimated). Depth, 386.

		Feet	
	From	To	Thickness
Joint clay	0	35	35
Dry sand	35	50	15
Joint clay	50	90	40
Blue gumbo	90	120	30
Joint clay	120	195	75
Gray sand	195	220	25
Red clay	220	245	25
Blue shale	245	250	5
Oil, sand	250	270	20
Blue shale	270	315	45
Sand	315	335	20
Blue shale	335	350	15
Oil, sand	350	360	10
Red mud	360	375	15

Blue shale	375	383	8
Oil, sand	383	386	3

No. 174.—Joyce No. 8. Clayco Oil & Pipe Line Co. Elevation, 930 (estimated). Depth, 386.

	Feet		
	From	To	Thickness
Clay	0	38	38
Sand rock	38	56	18
Clay	56	116	60
Oil and water, sand	116	134	18
Clay	134	253	119
Shale	253	260	7
Oil, sand	260	274	14
Clay	274	330	56
Oil, sand	330	337	7
Clay	337	375	38
Shale and sand	375	383	8
Oil, sand	383	386	3

No. 175.—Joyce No. 9. Clayco Oil & Pipe Line Co. Elevation, 930 (estimated). Depth, 266.

	Feet		
	From	To	Thickness
Joint clay	0	35	35
Dry sand	35	50	15
Joint clay	50	100	50
Blue shale	100	120	20
Sand, oil	120	130	10
Joint clay	130	170	40
Blue gumbo	170	200	30
Joint clay	200	240	40
Blue shale	240	251	11
Oil, sand	251	266	15

No. 176.—Joyce No. 10. Clayco Oil & Pipe Line Co. Elevation, 930 (estimated). Depth, 386.

	Feet		
	From	To	Thickness
Clay	0	46	46
Sand, rock	46	62	16
Clay	62	258	196
Oil, sand	258	266	8
Clay	266	310	44
Water, sand	310	322	12
Clay	322	378	56
Shale	378	383	5
Oil, sand	383	386	3

No. 177.—Joyce No. 11. Clayco Oil & Pipe Line Co. Elevation, 930 (estimated). Depth, 387.

	Feet		
	From	To	Thickness
Joint clay	0	35	35
Sand	35	50	15
Red mud	50	90	40
Blue shale	90	110	20
Sand	110	130	20
Blue gumbo	130	200	70
Red mud	200	245	45
Blue shale	245	250	5
Oil, sand	250	270	20
Blue shale	270	315	45
Water, sand	315	335	20
Blue shale	335	350	15
Red mud	350	375	25
Blue shale	375	384	9
Sand	384	387	3

No. 178.—Lone Star Gas No. 1. Lone Star Gas Co. Elevation, 929. Depth, 1684. Drilling commenced July 14, 1911. Drilling finished November 8, 1911. 287 feet of 12 1-2-inch casing; 1113 feet of 10-inch casing, 1661 feet of 8-inch casing. This was the largest gas well in the field, having a reported production of 30,000,000 cubic feet a day at a pressure of about 700 pounds per square inch, when drilled in. Plate IV.

	Feet		
	From	To	Thickness
Red mud	0	15	15
Hard rock	15	20	5
Mud cave and sand	20	410	390
Sand	410	435	25
Broken sand	435	570	135
Red mud	570	600	30
Red and blue cave	600	640	40
Sand	640	670	30
Blue mud	670	695	25
Red mud	695	700	5
Blue mud	700	705	5
Sand	705	740	35
Red cave	740	755	15
Blue cave	755	760	5
Sand	760	775	15
Mixture cave	775	925	150
Sand	925	935	10

Blue	935	958	23
Sand	958	968	10
Red and blue mixed	968	1120	152
Sand	1120	1135	15
Blue	1135	1195	60
Sand	1195	1200	5
Blue	1200	1215	15
Sand	1215	1275	60
Sand	1275	1285	10
Sand	1285	1295	10
Water, sand	1295	1430	135
Blue	1430	1470	40
Sand	1470	1480	10
Blue	1480	1490	10
Sand	1490	1510	20
Blue	1510	1580	70
Red	1580	1590	10
Blue, black	1590	1610	20
Sand	1610	1684	74

No. 179.—Miller Farm No. 1. Lone Star Gas Co. Elevation, 893. Depth, 1544. Drilling commenced August 27, 1909. Drilling finished November 14, 1909. 26 feet of 10-inch casing; 1502 feet of 6-inch casing; 17 feet of pipe below packer. Plate VI.

	Feet		
	From	To	Thickness
Red mud	0	10	10
Soft sand rock	10	12	2
Red sand	12	75	63
Soft sand rock	75	90	15
Red and blue shale, mixed	90	181	91
Missing	181	189	8
Blue shale	189	226	37
Hard sand rock	226	244	18
Red mud and gravel, mixed	244	384	140
Red mud and sand boulders	384	419	35
Red and blue shale	419	429	10
Red mud and gravel, mixed	429	509	80
Missing	509	617	108
Red mud and gravel	817	647	30
Red and blue shale	647	670	23
Red mud and gravel	670	698	28

Red and blue shale mixed	698	715	17
Red mud and gravel	715	744	29
Red and blue gumbo	744	760	16
Hard gravel and red mud, mixed	760	840	80
Red and sand boulders	840	855	15
Missing	853	915	60
Red mud and boulders	915	920	5
Red and blue mud and gravel, mixed	920	950	30
Blue rock and blue gumbo, mixed	950	1025	75
Blue gumbo	1025	1035	10
Blue shelly rock and gumbo	1035	1082	47
Blue gumbo and boulders	1082	1124	42
Hard blue granite	1124	1128	4
Blue gumbo	1128	1160	32
Water, sand	1160	1163	3
Blue granite	1163	1165	2
Missing	1165	1168	3
Hard black rock (broken)	1168	1204	36
Blue gumbo	1204	1215	11
Black sand rock	1215	1219	4
Blue gumbo and boulderes, mixed	1219	1260	41
Black slate	1260	1270	10
Oil sand (showing smell)	1270	1272	2
Hard black slate	1272	1302	30
Blue gumbo and boulders, mixed	1302	1362	60
White quartz	1362	1383	21
Blue mud and rock, mixed	1383	1408	25
Hard sand	1408	1412	4
Water, sand	1412	1422	10
Blue rock and mud, mixed	1422	1433	11
Black shelly rock	1433	1440	7
Hard sand rock	1440	1448	8
Blue boulders and mud, mixed	1448	1454	6
Hard black slate	1454	1488	34

Sand rock............	1488	1492	4
Blue mud and boulders, mixed	1492	1500	8
Sand rock.............	1500	1503-6	3′6″
Blue shale............	1503-6	1526	22′6″
Hard black slate and sand, mixed........	1526	1543	17
Gas, sand..............	1543	1544	1

No. 180.—Landrum No. 1. Sun Co. No data regarding this well could be obtained.

No. 181.—Landrum No. 2. Sun Co. Elevation, 955. Depth, 1549. This is a dry hole in what is considered proven territory. Plate VII.

	Feet		
	From	To	Thickness
Red clay.............	0	12	12
Hard rock............	12	18	6
Red clay.............	18	50	32
Hard rock............	50	62	12
Red clay, hard boulders	62	110	48
Hard rock, sand, salt water	110	115	5
Red clay, hard boulders	115	144	29
Hard rock, showing oil	144	149	5
Red clay..............	149	157	8
Salt, sand............	157	199	42
Red clay boulders.....	199	242	43
Sand rock, dry........	242	247	5
Red clay boulders....	247	286	39
Sand, rock............	286	288	2
Red and blue shale....	288	331	43
Salt water, sand.......	331	349	18
Red and blue shale.....	349	377	28
Sand, no water.......	377	385	8
Red shale.............	385	392	7
Sand, no water.......	392	398	6
Red shale.............	398	416	18
Boulders	416	417	1
Blue shale.............	417	441	24
Salt water, sand.......	441	450	9
Blue shale............	450	480	30
Sand, no water........	480	485	5
Blue shale............	485	532	47
Salt water, sand......	532	550	18
Blue shale............	550	552	2

Salt water, sand........	552	573	21
Blue shale............	573	579	6
Red and blue shale....	579	618	39
Salt water, sand.......	618	627	9
Red, blue and light shale	627	640	13
Oil, sand...............	640	654	14
Black sand...........	654	660	6
Red and blue shale....	660	700	40
Light shale...........	700	730	30
Red and blue shale....	730	780	50
Light shale...........	780	785	5
Oil, sand..............	785	795	10
Blue shale............	795	800	5
Light shale...........	800	840	40
Blue shale.............	840	859	19
Red and blue shale....	859	870	11
Salt water, sand.......	870	882	12
Dead sand............	882	890	8
Talc	890	899	9
Blue shale.............	899	920	21
Talc, resembles coffee grounds, very dark..	920	927	7
Blue shale............	927	930	3
Salt water, sand......	930	960	30
Blue shale............	960	982	22
Very hard black sand..	982	985	3
Blue shale.............	985	989	4
Red and blue shale...	989	1007	18
Blue shale............	1007	1024	17
Salt water, sand.......	1024	1036	12
Dead black sand......	1036	1045	9
Blue shale............	1045	1048	3
Dead black sand......	1048	1052	4
Red and blue shale....	1052	1073	21
Salt water, sand........	1073	1082	9
Blue shale............	1082	1098	16
Dead black sand.......	1098	1101	3
Very dark blue shale..	1101	1112	11
Red shale............	1112	1124	12
Light shale............	1124	1174	50
Red shale............	1174	1175	1
Dark blue shale.......	1175	1260	85
Light sand............	1260	1265	5
Salt water, sand.......	1265	1275	10
Blue shale.............	1275	1277	2
Salt water, sand......	1277	1456	179
Shale	1456	1549	93

No. 182.—Landrum No. 3. Sealy Oil Co. Elevation, 960 (estimated). Depth, 201.

	Feet From	Feet To	Thickness
Red clay	0	15	15
Dry sand	15	21	6
Light	21	34	13
Red clay	34	60	26
Water, sand	60	69	9
Red clay	69	71	2
Oil, sand	71	97	26
Red clay	97	111	14
Dry sand	111	118	7
Red clay	118	128	10
Dry sand	128	146	18
Red clay	146	150	4
Blue	150	154	4
Red clay	154	183	29
Water, sand	183	201	18
Red clay	201	...	..

No. 183.—Landrum Farm No. 3. Lone Star Gas Co. Elevation, 956. Depth, 1647. This is a producing gas well, seemingly shut off from the proven field by Well number 181. It seems probable that had No. 181 been drilled deeper, it would have struck the gas sand. Plate V.

	Feet From	Feet To	Thickness
Surface and red mud	1	12	12
Light colored rock	12	14	2
Red mud	14	40	26
Light colored rock	40	44	4
Red mud	44	78	34
Sand rock	78	81	3
Red mud	81	135	54
Light colored shale	135	160	25
Light colored rock	160	162	2
Oil, sand	162	167	5
Dead sand and showing little water	167	188	21
Blue shale	188	189	1
Salt water, sand	189	210	21
Red mud	210	260	50
Light colored shale	260	262	2
Oil, sand, very small	262	265	3
Red mud	265	330	65
Light colored shale	330	335	5

Red mud	335	340	5
Sand (some water and oil)	340	358	18
Light colored shale	358	366	8
Red mud	366	377	11
Light colored shale	377	395	18
Blue shale	395	400	5
Salt water, sand	400	415	15
Red and blue mud	415	465	50
Red mud	465	515	50
Light colored shale	515	550	35
Salt water, sand	550	565	15
Very hard sand	565	595	30
Red shale	595	610	15
Light colored shale	610	622	12
Red mud	622	630	8
Light colored shale	630	635	5
Red mud	635	740	105
Light colored shale	740	770	30
Blue shale	770	810	40
Light colored shale	810	849	39
Salt water, sand	849	868	19
Blue shale	868	870	2
Salt water, sand	870	912	42
Blue shale	912	960	48
Salt water, sand	960	983	23
Blue shale	983	993	10
Blue and red shale	993	1028	35
Salt water, sand	1028	1051	23
Blue shale	1051	1063	12
Blue and red shale	1063	1087	24
Black dead sand	1087	1092	5
Salt water, sand	1092	1098	6
Red and blue shale	1098	1208	110
Dead sand	1208	1213	5
Blue shale	1213	1265	52
Salt water, sand	1265	1276	11
Blue shale	1276	1278	2
Salt water, sand	1278	1283	5
Red and blue shale	1283	1385	102
Salt water, sand	1385	1422	37
Blue shale	1422	1427	5
Water, sand	1427	1433	6
Dark blue shale	1433	1613	80
Gas, sand	1613	1618	5
Broken sand and shale	1618	1630	12
Blue shale	1630	1633	3

Broken shale	1633	1640	7
Gas, sand	1640	1647	7

No. 184.—Byers No. 3. Producers Oil Co. Elevation, 975 (estimated). Depth to big salt sand, 1974 feet; reported thickness of sand below this, 536 feet; total depth, 2510 feet. This is a dry well, about two miles northeast of the proven field. The tools were still in salt sand when drilling was discontinued. Plate V.

No. 185.—Landrum No. 1, Lease No. 2. Clayo Oil & Pipe Line Co. Depth, 165. This was a dry hole.

	Feet		
	From	To	Thickness
Clay	0	12	12
Rock	12	20	8
Clay	20	154	134
Oil, sand	154	165	11

No. 186.—Landrum No. 2, Lease No. 2. Clayo Oil & Pipe Line Co. Depth, 184. See No. 185.

	Feet		
	From	To	Thickness
Clay	0	10	10
Rock	10	20	10
Clay	20	173	153
Oil and water, sand	173	184	11

No. 187.—Stine No. 1, Block 113. Depth, 878. This was a dry hole.

	Feet		
	From	To	Thickness
White sand	735	748	13
Salt, sand	748	756	8
Hard white sand	756	799	43
Hard rock	799	800	1
Salt, sand	800	814	14
Hard rock	814	818	4
White sand	818	827	9
Blue shale	827	858	31
Hard gray sand	858	861	3
Shale	861	862	1
Soft shale	862	874	12
White sand	874	878	4

No. 188.—Stine No. 2, Block 113. Depth, 945. See No. 187.

	Feet		
	From	To	Thickness
Clay, sand, rock	0	100	100
Gray sand	100	112	12
Mixed red clay and sand	112	200	88
Gray sand	200	209	9
Red rock and clay	209	249	40
Gray sand	249	256	7
Red rock and clay	256	535	279
White sand	535	545	10
Shale	545	742	197
White sand	742	748	6
Sand	748	870	122
Sand	870	875	5
Light sand	875	878	3
White sand	878	945	67

No. 189.—Matlock Farm No. 1. Lone Star Gas Co. Elevation, 943. Depth, 1644. Drilling commenced August 23, 1909. Drilling finished November 15, 1909. 11 feet of 10-inch casing; 1598 feet of 6-inch casing. Plate IV.

	Feet		
	From	To	Thickness
Red mud	0	14	14
Sand rock	14	18	4
Red mud, mixed	18	190	172
Sand rock	190	196	6
Red mud mixed	196	404	208
Flint rock	404	418	14
Red shale	418	470	52
Blue mud, mixed	470	482	12
Red mud	482	500	18
White rock	500	518	18
Red mud	518	550	32
Sand rock	550	572	22
Blue mud	572	595	23
Sand rock	595	612	17
Red mud	612	635	23
Flint rock	635	641	6
Blue shale	641	657	16
Sand rock	657	685	18
Red mud, mixed	685	705	20
Flint rock	705	715	10
Blue mud	715	740	25
Red mud	740	755	15
Blue shale	755	773	18
Oil, sand	773	776	3

Red mud	776	800	24
Sand rock	800	822	22
Blue mud	822	845	23
White rock	845	860	15
Blue shale	860	890	30
Red mud, mixed	890	915	25
Sand rock	915	940	25
Red mud	940	965	25
Blue shale	965	1000	35
Red mud	1000	1025	25
Sand rock	1025	1045	20
Red mud, mixed	1045	1073	28
Blue shale	1073	1105	32
Sand rock	1105	1130	25
Red mud, mixed	1130	1145	15
Sand rock	1145	1170	25
Blue shale	1170	1185	15
Sand rock	1185	1192	7
Blue shale	1192	1200	8
Oil and gas rock	1200	1204	4
Red mud, mixed	1204	1234	30
Blue shale	1234	1245	11
Oil, rock	1245	1248	4
Red mud	1248	1255	7
Sand rock	1255	1404	149
Red mud, mixed	1404	1440	36
Sand rock	1440	1465	25
Blue shale	1465	1530	65
Blue mud	1530	1550	20
Sand rock	1550	1565	15
Red mud	1565	1598	33
Flint rock	1598	1601	3
Blue shale	1601	1633	32
Oil and gas, sand	1633	1644	11

No. 190.—Wichita Oil & Gas Co. This is a gas well only about twenty feet shallower than Lone Star Gas Well No. 1, with a production of 16,000,000 cubic feet a day at a pressure of 450 pounds per square inch.

No. 191.—Schnell Farm No. 1. Lone Star Gas Co. Elevation, 910 (estimated). Depth, 1696. 420 feet of 10-inch casing; 1039 feet of 6-inch casing; 1433 feet 10 inches of 4-inch casing; 1696 feet of 2 1-2-inch pipe. Plate VII.

	Feet		
	From	To	Thickness
Red formation (set 10-inch casing at 420 on rock)	420	480	60

Hard sand rock......	480	495	15
Red formation........	495	540	45
Sand rock and clay...	540	770	230
Sand (some oil)......	770	790	20
Hard shale...........	790	805	15
Sand rock............	805	810	5
Red shale............	810	848	38
Sand rock...........	848	855	7
Red shale............	855	869	14
Sand rock............	869	885	16
Red shale and clay....	885	921	36
Sand rock...........	921	930	9
Red formation........	930	949	19
Sand rock............	949	957	8
Shale	957	972	15
Hard sand rock.......	972	978	6
Red formation........	978	1039	61
Hard sand rock.......	1039	1051	12
Red formation and rock	1051	1433	382
Sand rock............	1433	1435	2
Shale	1435	1445	10
Sand	1445	1457	12
Shale, light..........	1457	1481	24
Hard sand rock.......	1481	1484	3
Shale	1484	1488	4
Soft sand rock........	1488	1492	4
Shale, fine...........	1492	1498	6
Hard sand...........	1498	1501	3
Blue shale...........	1501	1532	31
Soft sand (some oil)...	1532	1538	6
Shale	1538	1567	29
Sand rock............	1567	1570	3
Red shale............	1570	1578	8
Sand (oil)...........	1578	1581	3
Shale	1581	1583	2
Hard sand rock.......	1583	1585	2
Shale, light..........	1585	1608	23
Oil sand (good)......	1608	1611	3
Shale, dark..........	1611	1634	23
Sand rock (little oil)..	1634	1642	8
Shale	1642	1675	33
Sand rock (some gas).	1675	1683	8
Broken sand, rock and shale	1683	1688	5
Very hard cap rock (lots of gas).......	1688	1696	8

No. 192.—Schnell Farm No. 2. Producers Oil Co. Elevation, 920 (estimated). Depth, 1832. This is a dry hole surrounded by producing wells. Plate VI.

No. 193.—Smith & Webber. Regarding this well, the only information obtainable was that it is a dry hole.

No. 194.—Matlock Lease No. 1. Producers Oil Co. Elevation, 943. Depth, 1920. This is a dry well in apparently proven territory. Plate VII.

No. 195.—Holloway No. 1. Producers Oil Co. Elevation, 942. Depth, 1828. See No. 194. Plate VII.

No. 196.—Home Oil Co. This is a dry well regarding which no further information could be secured.

No. 197.—Producers Oil Co. No information was available regarding this well except that it was a producing oil well.

No. 198.—Higgins Oil Co. This is a dry hole in apparently proven territory.

No. 199.—Schnell Farm No. 4. Lone Star Gas Co. Elevation, 900 (estimated). Depth, 1566. Drilling commenced Feb. 4, 1910. Drilling finished April 27, 1910. 1461 feet of 6-inch casing. 1540 feet of 4-inch casing. Plates IV and VI.

	Feet		
	From	To	Thickness
Water sand	420	430	10
Soft gray sand	430	470	40
Blue shale	470	580	110
Red mud and rock	580	585	5
Bed of sand boulders	585	588	3
Red mud and rock	588	670	82
Blue shale	670	690	20
Red mud and rock	690	750	60
Hard sand rock	750	830	80
Black slate	830	870	40
Bed of sand boulders	870	876	6
Sand rock	876	901	25
Soapstone	901	929	28
Red gravel and mud	929	944	15
Blue mud and boulders	944	974	30
Hard rock and red mud	974	1000	26
Blue granite	1000	1003	3

Blue mud and rock....	1003	1048	45
Blue granite.........	1048	1050	2
Hard sand rock.......	1050	1055	5
Blue mud and boulders	1055	1070	15
Blue shale...........	1070	1110	40
Bed of hard sand boulders	1110	1113	3
Hard sand rock.......	1113	1118	5
Blue mud and boulders	1118	1140	22
Gas sand............	1140	1142	2
Gumbo and rock.....	1142	1170	28
Blue shale...........	1170	1197	27
Hard sand rock.......	1197	1205	8
White mud and boulders	1205	1220	15
Black slate and sand...	1220	1232	12
Water sand..........	1232	1236	4
Blue mud and boulders	1236	1248	12
Blue gumbo..........	1248	1260	12
Hard sand rock......	1260	1262	2
Blue gumbo and rock.	1262	1279	17
Water sand..........	1279	1285	6
White mud and gravel.	1285	1300	15
Blue mud and rock...	1300	1310	10
Water sand..........	1310	1315	5
Blue mud and rock...	1315	1339	24
Water sand (show of oil)	1339	1354	15
Blue mud and rock....	1354	1362	8
Blue shale...........	1362	1377	15
Blue mud and rock....	1377	1423	46
Black sand boulders...	1423	1426	3
Hard sand rock.......	1426	1430	4
Blue mud and boulders	1430	1445	15
Broken slate and sand.	1445	1450	5
Blue tough mud......	1450	1458	8
Black soft sand.......	1458	1459	1
Hard sand...........	1459	1461	2
Broken sand and slate.	1461	1483	22
Blue shale...........	1483	1493	10
Black slate...........	1493	1501	8
Blue mud............	1501	1518	17
Black slate...........	1518	1524	6
Blue gumbo..........	1524	1537	13
Hard cap rock........	1537	1540	3
Gas sand............	1540	1566	26

No. 200.—Holloway Farm No. 2. Lone Star Gas Co. Elevation, 920 (estimated). Depth, 1744. Drilling commenced July 7, 1910. Drilling finished Nov. 19, 1910. 212 feet of 12 1-2-inch casing; 764 feet of 10-inch casing; 1350 feet of 8-inch casing; 1742 feet of 6-inch casing. Plates IV and VI.

	Feet		
	From	To	Thickness
Soil	0	2	2
Red clay............	2	70	68
Sand, water..........	70	75	5
Red clay.............	75	185	110
Sand, water..........	185	210	25
Red clay.............	210	375	165
Sand, water..........	375	385	10
Red clay.............	385	425	40
Blue mud............	425	440	15
Red clay.............	440	475	35
Sand, water..........	475	495	20
Blue mud............	495	560	65
Sand, water..........	560	575	15
Blue mud............	575	580	5
Sand, water..........	580	625	45
Mixture	625	710	85
Gray	710	740	30
Red, cave............	740	765	25
Sand, dry............	765	775	10
Red	775	805	30
Sand, dry............	805	815	10
Mixture	815	895	80
Blue	895	905	10
Sand, dry............	905	915	10
Mixture	915	975	60
Blue	975	1020	45
Sand, water..........	1020	1050	30
Blue	1050	1095	45
Mixture	1095	1200	105
Red	1200	1210	10
Blue	1210	1270	60
Sand, water..........	1270	1320	50
Blue	1320	1350	30
Blue	1350	1505	155
Sand, gas............	1505	1520	15
Blue shale...........	1520	1600	80
Sand, gas............	1600	1630	30
Blue	1630	1640	10
Sand, oil............	1640	1664	24
Sand, gas............	1664	1674	10

Shale	1674	1680	6
Blue shale	1680	1690	10
Red rock	1690	1710	20
Sand, oil	1710	1742	32
Slate	1742	1744	2

No. 201.—Van Winkle No. 1. Lone Star Gas Co. Elevation, 882. Depth, 1725. Drilling commenced Feb. 9, 1910. Drilling finished June 2, 1910. 67 feet of 10-inch casing; 1308 feet of 6-inch pipe; 1431 feet of 4-inch pipe; pulled most of this. This well is south of the producing field and was a dry hole. Plate VII.

	Feet		
	From	To	Thickness
Red mud	0	59	59
Sand rock	59	63	4
Red mud	63	70	7
Sand rock	70	142	72
Red mud	142	172	30
Sand rock	172	180	8
Oil sand	180	185	5
Red mud	185	226	41
Sand rock	226	238	12
Blue shale	238	336	98
Sand rock	336	376	40
Gypsum	376	381	5
Red mud mixed	381	436	55
Sand rock	436	473	37
Blue shale	473	501	28
Sand rock	501	507	6
Blue shale	507	554	47
Sand rock	554	580	26
Red mixed mud	580	604	24
Sand rock	604	609	5
Blue mud mixed	609	723	114
Sand rock	723	729	6
Red mud mixed	729	768	39
Sand rock	768	858	90
White mud	858	864	6
Red mud, mixed	864	925	61
Sand rock	925	941	16
Missing	941	951	10
Sand rock	951	979	28
Blue mud	979	989	10
Sand rock	989	991	2
Blue mud, mixed	991	1005	14
Sand rock	1005	1010	5

Blue mud, mixed	1010	1017	7
Sand rock	1017	1023	6
Red sand, mixed	1023	1058	35
Sand rock	1058	1084	26
Blue mud	1084	1092	8
Sand rock	1092	1102	10
Flint rock	1102	1106	4
Red mud, mixed	1106	1148	42
Blue shale	1148	1160	12
Dead sand	1160	1162	2
Blue shale	1162	1203	41
White mud, mixed	1203	1225	22
Sand rock	1225	1236	11
Red mud, mixed	1236	1263	27
Blue shale	1263	1306	43
Hard sand rock	1306	1311	5
Blue shale	1311	1373	62
Sand rock	1373	1377	4
Blue shale	1377	1405	28
Red mud, mixed	1405	1415	10
Blue shale	1415	1430	15
Hard sand rock	1430	1437	7
Dark blue shale	1437	1457	20
Dark shale and sand, mixed	1457	1476	19
Sand rock	1476	1478	2
Dark shale and sand, mixed	1478	1576	98
Dead sand	1576	1579	3
Dark shale and sand, mixed	1579	1583	4
Dark sand	1583	1585	2
Dark shale and sand, mixed	1585	1605	20
Dead sand	1605	1611	6
Dark shale and sand, mixed	1611	1651	40
Hard sand rock	1651	1653	2
Dark shale	1653	1663	10
Gas sand	1663	1670	7
Black shale	1670	1682	12
Gas sand	1682	1686	4
Dark shale	1686	1693	7
Oil sand	1693	1695	2
Hard sand rock	1695	1697	2
Dark shale	1697	1705	8
Water sand	1705	1725	20

No. 202.—Taylor No. 2. Lone Star Gas Co. Elevation, 941. Depth, 1815. Drilling commenced July 19, 1910. Drilling finished Oct. 10, 1910. 42 feet of 10-inch casing; 1721 feet of 6-inch line pipe; 80 feet of 4 1-2-inch drive pipe. Plate VI.

	Feet		
	From	To	Thickness
Surface clay	0	23	23
Sand rock	23	190	167
Soft white rock	190	210	20
Sand rock and blue shale	210	230	20
Soft white sand rock	230	252	22
Sand rock	252	292	40
Red and blue mud	292	335	43
White sand, rock and shale	335	355	20
Hard sand rock and shale, mixed	355	382	27
Soft sand rock	382	416	34
Hard sand rock	416	437	21
Blue mud	437	476	39
Red shale	476	514	38
Hard sand rock	514	533	19
Hard blue mud	533	554	21
Red clay	554	597	43
Blue shale	597	655	58
Hard sand rock	655	676	21
Soft sand rock	676	695	19
Red mud	695	736	41
Brown shale	736	757	21
Soft white sand rock	757	782	15
Brown shale	782	825	43
Hard red mud	825	906	81
Sand rock and blue shale	906	944	38
Red mud	944	965	21
Sand rock and blue shale	965	987	22
Hard sand rock	987	1029	42
Hard blue shale	1029	1090	61
Hard red mud	1090	1132	42
Hard red sand rock	1132	1153	21
Hard sand rock and shale	1153	1171	18
Hard blue mud	1171	1195	24
Sand rock	1195	1219	24

Sand rock and shale...	1219	1322	103
Sand rock............	1322	1385	63
Red mud.............	1385	1406	21
Blue shale............	1406	1468	62
Soft blue shale.......	1468	1489	21
Red gumbo (mud)....	1489	1511	22
Hard sand rock.......	1511	1547	36
Hard blue mud.......	1547	1588	41
Blue shale and boulders	1588	1609	21
Sand rock...........	1609	1627	18
Hard blue mud.......	1627	1643	16
Hard rock...........	1643	1658	15
Hard gypsum rock....	1658	1676	18
Hard red mud........	1676	1693	17
Hard sand rock and shale	1693	1711	18
Hard sand rock......	1711	1725	14
Blue shale...........	1725	1752	27
Gas sand (oil in last 8 feet)	1752	1764	12
Hard blue shale......	1764	1770	6
Blue shale...........	1770	1815	45
Sand rock (stopped drilling)	1815	....	..

No. 203.—Taylor No. 4. Producers Oil Co. Elevation, 941. Depth, 1766. This was a combination gas and oil well, yielding 12 barrels of oil the first 24 hours. Plate VI.

No. 204.—Taylor No. 3. Producers Oil Co. Elevation, 937. Depth, 1761. This was a small gas well. Plate VI.

No. 205.—Taylor No. 1. Producers Oil Co. Beyond the fact that this was a dry well, no information could be secured.

No. 206.—Holloway, drilling.

No. 207.—Dunn No. 1. Guffey Petroleum Co. Elevation, 934. Depth, 1754. Drilling commenced Aug. 1, 1910. Drilling finished Dec. 17, 1910. 240 feet of 10-inch casing; 1058 feet of 8-inch casing; 1722 feet of 6-inch casing. This well and Dunn No. 2 are the largest producers of oil in the Petrolia field and yield from a greater depth than any other wells. Plate VII.

	Feet		
	From	To	Thickness
Clay	0	16	16
Rock	16	23	7
Red clay............	23	44	21

Rock	44	75	31
Clay	75	81	6
Rock	81	95	14
Clay	95	112	17
Rock	112	115	3
Clay	115	155	40
Rock	155	181	26
Clay	181	215	34
Rock	215	232	17
Clay	232	276	44
Rock	276	280	4
Clay	280	312	32
Rock	312	320	8
Clay	320	398	78
Rock	398	417	19
Clay	417	481	64
Sand rock	481	485	4
Hard blue shale	485	512	27
Sand rock	512	534	22
Hard blue shale	534	556	22
Rock	556	582	26
Hard blue shale	582	608	26
Rock	608	618	10
Blue shale	618	647	29
Rock	647	658	11
Hard shale	658	694	36
Rock	694	699	5
Red clay	699	720	21
Rock	720	724	4
Hard blue shale	724	768	44
Rock	768	772	4
Blue shale	772	790	18
Rock	790	843	53
Shale and clay	843	882	39
Rock	882	888	6
Hard blue shale	888	905	17
Rock	905	921	16
Hard blue shale	921	933	12
Rock	933	957	24
Hard blue shale	957	962	5
Rock	962	964	2
Hard blue shale	964	1020	56
Rock	1020	1025	5
Hard blue shale	1025	1058	33
Rock	1058	1060	2
Hard blue shale	1060	1108	48
Rock	1108	1110	2

Hard blue shale	1110	1137	27
Rock	1137	1141	4
Hard shale	1141	1184	43
Rock	1184	1196	12
Hard shale	1196	1204	8
Rock	1204	1208	4
Shale	1208	1232	24
Hard shale	1232	1243	11
Rock	1243	1264	21
Hard blue shale	1264	1276	12
Rock	1276	1277	1
Shale	1277	1281	4
Rock	1281	1308	27
Shale and boulders	1308	1330	22
Rock	1330	1334	4
Gumbo	1334	1356	22
Hard shale	1356	1396	40
Rock	1396	1402	6
Gumbo	1402	1504	102
Shale and boulders	1504	1520	16
Shale and boulders	1520	1600	80
Rock, showing gas	1600	1618	18
Gumbo, shale and loose boulders	1618	1679	61
Rock, or loose bed of boulders	1679	1686	7
Soft rotten shale (steel line measurement) with salt streaks	1686	1718	32
Shell rock	1718	1722	4
Hard shale	1728	1741	19
Hard sand rock, showing gas	1741	1744	3
Oil sand	1744	1754	10

No. 208.—Dunn No. 2. Guffey Petroleum Co. Elevation, 936. Depth, 1760. Drilling commenced Jan. 29, 1911. Drilling finished April 13, 1911. 221 feet of 10-inch casing; 1705 feet of 6-inch casing. See note on No. 207. Plate VI.

	Feet		
	From	To	Thickness
Clay, sand, rock and gumbo	0	266	266
Shale	266	271	5
Rock	271	275	4
Hard shale	275	480	205
Rock	480	484	4

Hard shale	484	510	26
Rock	510	515	5
Hard shale	515	562	47
Rock	562	585	23
Hard shale	585	602	17
Rock	602	612	10
Gumbo	612	632	20
Rock	632	647	15
Hard shale	647	652	5
Sand rock	652	672	20
Gumbo	672	710	38
Sand rock	710	725	15
Shale	725	755	30
Gumbo	755	828	73
Rock	828	866	38
Gumbo	866	925	59
Rock	925	937	12
Hard sand	937	958	21
Gumbo	958	1048	90
Rock	1048	1055	7
Gumbo	1055	1120	65
Sand rock	1120	1140	20
Rock	1140	1148	8
Gumbo	1148	1185	37
Rock	1185	1192	7
Gumbo and boulders	1192	1198	6
Sandy shale, showing some oil	1198	1240	42
Gumbo and boulders	1240	1248	8
Rock	1248	1270	22
Gumbo and boulders	1270	1295	25
Rock	1295	1310	15
Gumbo and boulders	1310	1355	45
Sand and shale	1355	1388	33
Gumbo	1388	1575	187
Shale	1575	1620	45
Hard sand rock, showing gas	1620	1630	10
Gumbo and boulders	1630	1643	13
Rock	1643	1648	5
Second gas sand rock	1648	1656	8
Gumbo and boulders	1656	1675	19
Salt and shale	1675	1688	13
Hard rock	1688	1691	3
Soft shale	1691	1705	14
Gumbo	1705	1718	13

Soft rotten shale, showing some oil	1718	1738	20
Gumbo	1738	1745	7
Hard oil sand	1745	1754	9
Gumbo	1754	1755	1
Sand rock	1755	1756	1
Hard oil sand	1756	1759	3
Gumbo	1759	1760	1

No. 209.—Fultz No. 1. This is a shallow dry hole.

No. 210.—McAllister No. 1. This is a dry hole.

No. 211.—Fultz No. 2. Sealey Oil Co. Elevation, 910 (estimated). Depth, 250.

	Feet		
	From	To	Thickness
Red clay	0	10	10
Water sand	10	17	7
Red clay	17	21	4
Water sand	21	49	28
Red clay	49	86	37
Dry sand	86	91	5
Extra red clay	91	107	16
Light blue	107	131	24
Red clay	131	139	8
Blue	139	148	9
Red clay	148	174	26
Light	174	195	21
Red clay	195	226	31
Water sand	226	239	13
Yellow	239	250	11

No. 212.—Holloway No. 3. Producers Oil Co. Elevation, 908. Depth, 1900. This is a dry well, somewhat southeast of the proven field. Plate IV.

No. 213.—Stine No. 1, Block 19. Producers Oil Co. Elevation, 940. Depth, 1928. A big salt sand was struck here. It is said this well is to be drilled deeper. Plate VI.

No. 214.—Sealey Co. No information could be secured regarding this well.

No. 215.—Brummett Ellis and Co. No. 1. Elevation, 880 (estimated). Depth, 342.

	Feet		
	From	To	Thickness
Clay	0	20	20
Water sand	20	28	8
Clay	28	35	7
Sand rock	35	100	65
Clay	100	120	20
Oil sand	120	125	5
Clay	125	318	193
Salt water sand	318	342	14

No. 216.—Parker No. 1. Fort Worth Oil Co. No data could be obtained regarding this well.

No. 217.—Smyers No. 1. Depth, 1586. This well is about three miles east a little south of Byers Station and is a dry hole.

	Feet		
	From	To	Thickness
Red mud	0	25	25
Hard sand rock	25	50	25
Red mud	50	60	10
Sand rock	60	100	40
Blue mud	100	125	25
Hard sand rock	125	200	75
Rock	200	350	150
Shale	350	400	50
Soft blue mud	400	500	100
Hard sand rock	500	540	40
Hard rock	540	700	160
Soft shale	700	750	50
Hard sand rock	750	1000	250
Soft red shale	1000	1090	90
Red mud	1090	1100	10
Soft shale	1100	1180	80
Sand rock	1180	1190	10
Hard sand rock	1190	1200	10
Soft sandstone	1200	1300	100
Hard rock	1300	1355	55
Hard sand rock	1355	1375	20
Clay, light blue	1375	1385	10
Soft sand rock	1385	1401	16
Red mud	1401	1418	17
Clay, light blue	1418	1424	6
Soft rock	1424	1433	9
Rock	1433	1443	10
Clay	1443	1452	9

Soft rock	1452	1458	6
Clay	1458	1472	14
White rock	1472	1480	8
White rock	1480	1485	5
Clay	1485	1500	15
Gritty mud	1500	1504	4
Hard sand rock	1504	1506	2
Clay	1506	1512	6
Gritty mud	1512	1516	4
Soft white rock	1516	1530	14
Gritty mud	1530	1532	2
Soft white rock	1532	1550	18
Clay	1550	1558	8
Hard flint rock	1558	1562	4
Gritty mud	1562	1564	2
Soft rock	1564	1570	6
Gritty mud	1570	1575	5
Soft white rock	1575	1586	11

No. 218.—Singer No. 1. No information could be obtained relating to this well.

No. 219.—Lankford No. 1. Edmond Oil Co. No information could be obtained relating to this well.

No. 220.—Moser No. 1. Producers Oil Co. No information was obtainable.

No. 221.—Douthitt No. 1. Producers Oil Co. This is a dry hole, regarding which no further information could be secured.

No. 222.—Boddy No. 1. Corsicana Petroleum Co. Elevation, 844. Depth, 1770. This is a dry well, about seven miles northeast of Henrietta. Plate XIII.

		Feet	
	From	To	Thickness
Red clay	0	40	40
Quicksand	40	50	10
Red mud	50	125	75
Gray sand	125	145	20
Red mud	145	170	25
Soapstone	170	200	30
Red mud	200	230	30
White mud	230	250	20
Red mud	250	290	40
White sand	290	305	15
White mud	305	320	15

Red mud	320	350	30
White mud	350	400	50
White sand	400	410	10
White mud	410	440	30
Red mud	440	480	40
White mud	480	490	10
White sand	490	520	30
Red mud	520	550	30
White mud	550	590	40
Soapstone	590	630	40
Red mud	630	670	40
White mud	670	729	59
Red mud	729	739	10
White sand	739	740	1
Sand (some gas)	740	765	25
Blue shale	765	876	111
Sand	876	900	24
Red mud	900	930	30
White slate	930	945	15
Red mud	945	1000	55
White mud	1000	1065	65
White sand	1065	1075	10
White sand	1075	1180	105
White sand salt	1180	1228	48
Red mud	1228	1355	127
Sand	1355	1380	25
Gray slate	1380	1410	30
Sand, some oil	1410	1418	8
Red mud	1418	1436	18
Sand	1436	1465	29
Blue shale	1465	1476	11
Shale and rock	1476	1490	14
Flint rock	1490	1502	12
Blue shale	1502	1541	39
Slate and rock	1541	1565	24
Sand, some gas	1565	1579	14
Red mud	1579	1589	10
Sand rock	1589	1601	12
Blue shale	1601	1620	19
Shale and rock	1620	1651	31
Sand	1651	1665	14
Shale	1665	1679	14
Red shale	1679	1703	24
Sand	1703	1712	9
Blue mud	1712	1741	29
Blue shale	1741	1752	11
Sand rock	1752	1770	18

No. 223.—Myers Farm No. 1. Producers Oil Co. Elevation, 926. Depth, 2180. Drilling commenced May 27, 1909. Drilling finished Dec. 31, 1909. 176 feet of 12 1-2-inch casing; 589 feet of 10-inch casing; 1310 feet of 8-inch casing; 1942 feet of 6-inch casing. This is a dry hole about one mile southwest of the station at Henrietta. Plate XIII.

	Feet		
	From	To	Thickness
Red mud............	0	280	280
Gray water sand......	280	300	20
Red cave............	300.	415	115
Gray slate...........	415	425	10
Red cave............	425	500	75
White water sand.....	500	525	25
Red cave............	525	535	10
Broken sand.........	535	550	15
Gray salt sand.......	550	565	15
Red cave............	565	575	10
White slate..........	575	590	15
Red and white, mixed.	590	615	25
Salt water sand.......	615	636	21
Red cave............	636	655	19
White slate..........	655	675	20
Red and blue mud....	675	685	10
White slate..........	685	700	15
Red cave............	700	705	5
White slate..........	705	710	5
White salt sand......	710	735	25
Broken gray sand.....	735	745	10
Hard brown sand, trace of oil............	745	755	10
Loose white sand.....	755	800	45
Broken gray sand....	800	810	10
Red cave............	810	820	10
White slate and shell..	820	825	5
Red cave............	825	845	20
Gray shells..........	845	855	10
Red cave............	855	865	10
White sand..........	865	875	10
Water sand..........	875	885	10
Slate	885	890	5
Dark gray shells......	890	900	10
Light slate..........	900	910	10
Red bed............	910	925	15
Very white sand......	925	940	15
Red rock............	940	955	15
Gray water sand......	955	975	20

Blue slate	975	980	5
Red rock	980	1005	25
Blue slate	1005	1010	5
Sand, white	1010	1020	10
Red marl, streaks of blue shale	1020	1030	10
Sand, light gray	1030	1040	10
Red marl	1040	1055	15
Sand, gray, dry	1055	1060	5
Red marl	1060	1085	25
Sand, white salt water	1085	1100	15
Sand, broken	1100	1115	15
Sand, soft, white	1115	1125	10
Broken sand	1125	1140	15
Blue slate	1140	1150	10
Sand, dry, white	1150	1155	5
Dark blue slate	1155	1180	25
Sand streaks, light slate	1180	1200	20
Red marl	1200	1225	25
Sand, gray	1225	1230	5
Red marl	1230	1270	40
Brown shells	1270	1280	10
Red marl	1280	1330	50
Sand, brown	1330	1350	20
Blue slate	1350	1380	30
Red marl with streaks of white sand shells	1380	1470	90
Brown slate	1470	1495	25
White slate	1495	1606	111
Sand, white, salt water	1606	1628	22
Blue shale	1628	1648	20
Sand, white, salt water	1648	1663	15
Blue shale	1663	1700	37
White shale	1700	1715	15
Sand, white, salt water	1715	1727	12
Black gumbo	1727	1737	10
Gray sand	1737	1744	7
Blue shale	1744	1790	46
Sand with streaks of blue shale	1790	1810	20
Sand, white, with salt water	1810	1820	10
Blue shale	1820	1840	20
Sand, gray	1840	1850	10
Blue slate, streaks of black slate	1850	1930	80

Blue slate	1930	2173	243
Sand, gray, with salt water	2173	2180	7

No. 224.—Huggins Oil Co. No data could be obtained relating to this well.

No. 225.—Huggins No. 1. Producers Oil Co. Elevation, 820 (estimated). Depth, 2149. This is a dry hole near the Red River, about 12 miles southeast of Petrolia. Plate XIII.

	Feet		
	From	To	Thickness
Yellow clay	0	20	20
Sand and red marl with water	20	40	20
Quicksand	40	45	5
Red marl	45	350	305
White sand	350	360	10
Red marl and rock	360	390	30
Salt water, sand	390	410	20
Red marl	410	475	65
White sand	475	490	15
Red marl	490	540	50
White salt water sand	540	555	15
Red marl	555	585	30
White sand with streaks of lime	585	700	115
Blue shale, hard to mix	700	750	50
Limeshells, with streaks of white sand	750	760	10
Red marl	760	810	50
Soft white sand	810	820	10
Red marl	820	960	140
Salt water sand	960	1065	105
Blue shale	1065	1170	105
Salt water sand	1170	1190	20
Red marl	1190	1220	30
Gray sand	1220	1225	5
Blue gumbo	1225	1245	20
Salt sand, white	1245	1275	30
Blue gumbo	1275	1285	10
Blue shale	1285	1295	10
Red shale and rock	1295	1310	15
Blue gumbo	1310	1325	15
White soapstone	1325	1337	12
Sand, white, dry	1337	1342	5

Red marl and rock....	1342	1470	138
Blue shale............	1470	1504	34
Sand, white..........	1504	1519	15
Blue shale...........	1519	1550	31
Sand, white..........	1550	1560	10
Blue shale...........	1560	1610	50
Water sand..........	1610	1630	20
Blue shale...........	1630	1690	60
Sand, white, salt water	1690	1700	10
Blue shale...........	1700	1790	90
Sand, white..........	1790	1810	20
Slate	1810	1840	30
Sand, dry............	1840	1845	5
Brown shale.........	1845	1892	47
Sand shells..........	1892	1895	3
Light blue shells......	1895	1920	25
Brown sand..........	1920	1925	5
Brown shale..........	1925	2147	122
Sand, white, salt water	2147	2149	2

No. 226.—Bellevue Oil and Gas Co. No. 1. The well is about three miles north of Bellevue and is dry. Plate XIII.

Samples examined:

2030-2038.—Gray, yellow, blue and yellowish sand and some gray limestone. Shell fragments, spines of brachiopods, and one crinoid joint were noted.

		Feet	
	From	To	Thickness
Soft red..............	0	73	73
Gray sand............	73	77	4
Soft red..............	77	105	28
Soft water, sand......	105	135	30
Soft red..............	135	175	40
Soft sandy shale.......	175	218	43
Soft red..............	218	226	8
Soft sand shale........	226	285	59
Soft yellow...........	285	320	35
Soft red..............	320	379	59
Soft gray shale........	379	395	16
Soft red..............	395	423	28
Soft blue shale........	423	451	28
Soft gray shale.......	451	467	16
Soft gray sand........	467	489	22
Soft red..............	489	530	41
Soft gray sand.........	530	551	21
Soft red..............	551	570	19
Soft yellow shale.......	570	593	23

Soft red..............	593	610	17
Soft sand..............	610	640	30
Soft blue shale........	640	663	23
Soft gray sand........	663	667	4
Soft gray shale sand...	667	688	21
Soft gray sand.........	688	708	20
Blue shale............	708	739	31
Soft gray sand........	739	766	27
Blue shale............	766	825	59
Brown shale..........	825	838	13
Gray sand............	838	853	15
Blue shale.............	853	871	18
Gray sand............	871	889	18
Blue shale............	889	915	26
Gray sandy shale......	915	931	16
Brown shale..........	931	947	16
Soft blue shale.........	947	963	16
Gray sand............	963	970	7
Sandy shale..........	970	976	6
Blue shale............	976	1040	64
Brown shale..........	1040	1054	14
Gray shale.............	1054	1061	7
Brown shale...........	1061	1072	11
Gray sand..............	1072	1084	12
Brown shale..........	1084	1105	21
Blue slate.............	1105	1127	22
Gray sand............	1127	1143	16
Blue slate............	1143	1202	59
Hard lime shell.........	1202	1206	4
Red shale..............	1206	1220	14
Blue shale............	1220	1298	78
Gray sand.............	1298	1302	4
Blue shale............	1302	1360	58
Gray sand............	1360	1378	18
Blue shale.............	1378	1403	25
Hard lime shell.......	1403	1405	2
Blue shale............	1405	1419	14
Black shale...........	1419	1438	19
Blue shale............	1438	1476	38
Black shale............	1476	1518	42
Blue shale............	1518	1538	20
Hard lime shell........	1538	1540	2
Blue shale............	1540	1710	170
Brown shale..........	1710	1803	93
Blue shale.............	1803	1830	27
Brown shale....... ..	1830	1845	15
Hard gray lime........	1845	1860	15

Soft blue shale	1860	1878	18
Gray shale	1878	1893	15
Blue shale	1893	1924	31
Brown shale	1924	1957	33
Blue shale	1957	1981	24
Brown shale	1981	2005	24
Gray sand	2005	2013	8
Blue shale	2013	2015	2
Hard lime	2015	2032	17
Blue shale	2032	2060	28
Brown shale	2060	2092	32
Blue shale	2092	2127	35
Hard gray sand	2127	2130	3

APPENDIX II.

NATURAL GAS FROM CLAY COUNTY,

HENRIETTA-PETROLIA FIELD.

BY

WM. B. PHILLIPS, Director.

Inasmuch as the Bureau of Economic Geology and Technology expects to issue within the next few months a special Bulletin dealing with gaseous fuels in Texas, both natural and manufactured, it is not necessary to enter, in detail, upon this subject now. But as certain analyses of crude petroleum from Wichita and Clay Counties have been given in this Bulletin and as many references have been made to the gas fields at Petrolia, Clay County, it has been thought best to give a few analyses of the gas from this field, with a brief account of the use of this gas in north Texas.

On the 16th and 23d of January, 1912, two analyses of natural gas from Clay County were received from the Dallas Gas Company. They were made by the United Gas Improvement Company, Philadelphia, and were as follows:

Carbon dioxide	0.20	none
Illuminants	0.30	0.30
Ethane	12.50	5.50
Oxygen	0.40	0.20
Carbon monoxide	....	0.30
Hydrogen	0.80	1.00
Methane	47.20	55.90
Nitrogen (by diff.)	38.60	36.80
	100.00	100.00
Specific gravity	....	0.72

Mr. W. M. Russell, City Gas Inspector, Fort Worth, made an analysis of the Clay County natural gas in 1909 as follows:

Carbon dioxide	none
Illuminants	0.80
Oxygen	0.70
Carbon monoxide	trace
Hydrogen	67.93
Methane	trace
Nitrogen (by diff.)	31.57
	101.00

On June 4th, 1912, an analysis of the natural gas supplied to the City of Dallas, from Clay County, was made by Mr. S. H. Worrell, Chemist to the Bureau. The results were as follows:

Carbon dioxide	none
Illuminants	none
Oxygen	none
Carbon monoxide	none
Hydrogen	none
Methane	56.80
Nitrogen (by diff.)	43.20
	100.00

In the Junkers Continuous Gas Calorimeter this gas gave 649 B. T. U. per cubic foot.

In a communication from Mr. N. C. Hamner, Consulting and Analytical Chemist, Dallas,. who is also City Chemist. under date of August 14th, 1912, he says: "I have made a number of determinations of the heat value (*he speaks of the natural gas supplied to Dallas from Clay County. W. B. P.*) by means of the Junkers Calorimeter and find it to run about 740 B. T. U. at 0° C. and 29.8 inches of mercury. We calculate to this on account of the fact that the franchise calls for not less than 633 B. T. U. at 0° C. and 29.8 inches of mercury."

The Lone Star Gas Company, Fort Worth, informs us that the average composition of the natural gas from Clay County is about as follows:

Carbon dioxide	0.20
Illuminants	0.30
Oxygen	0.40
Carbon monoxide	0.00
Hydrogen	0.80
Methane	47.20
Ethane	12.50
Nitrogen (by diff.)	38.60
	100.00

This gas is now supplied to the following cities and towns in north Texas by the Lone Star Gas Company: Arlington, Alvord, Bellevue, Bowie, Bridgeport, Byers, Dallas, Dalworth, Decatur, Fort Worth, Grand Prairie, Henrietta, Irving, Petrolia, Rome, Sunset, Wichita Falls. In addition to this service this company is now extending its lines to other cities and towns.

The Wichita Falls Gas Company, Wichita Falls, supplies that city from its wells in Clay County.

It is likely that during the next few months there will be a marked increase in the number of cities and towns in north Texas to be supplied with natural gas, such as Denison, Sherman, Denton, Gainesville, Cleburne, Vernon, Chillicothe, Quanah, and, perhaps, even as far west as Amarillo.

The present piping distance to Dallas is about 125 miles.

The production of natural gas in Texas, 1911, was about 5½ thousand million cubic feet, valued at a little over $1,000,000, by far the greater part coming from Clay County.

The rates for natural gas in Dallas, effective February 14, 1912, were as follows: net, minimum bill per meter per month:

First 10 M. cu. ft.	45 cents per M.
Next 5 M. cu. ft.	40 cents per M.
Next 15 M. cu. ft.	35 cents per M.
Next 70 M. cu. ft.	30 cents per M.
Next 900 M. cu. ft.	20 cents per M.
All over 1000 M. cu. ft.	14 cents per M.

Schedule (A.) boiler rates on term contract, guaranteed minimum bill $60.00 per month:

First 250 M. cu. ft. net	20 cents per M.
All in excess of 250 M. cu. ft. per meter per month	10 cents per M.

Schedule (B.) boiler rates on yearly contract, guaranteed minimum bill $1,200 per annum: 9 cents, net, per M.

Some contracts at Wichita Falls, about 20 miles from the wells in Clay County, have been placed at rates varying from 5 to 7 cents per M. cu. ft. and it is reported that a lower rate would be offered to industrial establishments consuming large quantities of the gas.

LIST OF WELLS.

Baylor County.

Well No.	Name	Page	Plate
1	Webb No. 1, Devonian Oil Co.	120	

Wilbarger County.

Well No.	Name	Page	Plate
2	Webb No. 1, Guffey Pet. Co.	121	
3	Allingham No. 1, Electra Oil Field Co.	121	
4	Tate No. 1, P. O. C.	121	
5	Waggoner No. 7, P. O. C.	122	
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Surviving analytical complexes.

The process of evolution in language, like the biological process, starts with a minimum of origination; advances with a maximum of adaptation combination development; ends in what appears to us as greater functional precision and simplification or, in the inevitable metaphor of our manner of speaking, decay and loss.

1. In the following pages I shall attempt to show how the IE. verbal flexion grew out of analytical complexes of rootnouns, in infinitival and participial function, followed by the normal forms of the verbs 'ire', 'esse', 'stare', etc. Such groups were more nearly like modern English than Homeric Greek. These complexes were finally isolated into the forms we now interpret as presents, futures, perfects, aorists, desideratives, middles. Phonetic phenomena such as haplology, sometimes of the not quite perfect sort seen in Lat. *ex(sec)ta*, are largely in evidence, but of specific new assumptions I have made but three: 1st, on the basis of the samdhi variation between the final diphthong *-e* and *-a* in Sanskrit, that doublets like ἄγε : Doric ἄγει, vocatives like νύμφα : Skr. *kánye*, 1st person perfects like οἶδα : Lat. *videi*, 2d person οἶσθα : *vidisti* are phenomena of IE. samdhi; 2d, that when nominatival -s was followed in a complex by a vowel initial it yielded s^s; 3d, that an IE. compound, formed and isolated during the period when an accented syllable was causing in its predecessor the weakening that we call the zero-grade, would suffer loss of any short vowel, whether I or U, in the pretonic position.

2. The IE. complexes that I have assumed do not range more widely than such historically attested instances as the following in Greek (examples chiefly extracted from Goodwin's Greek Moods and Tenses 772, 830, 895): (1) ἐπίτεξ ἐοῦσα (Hdt.) quasi 'parturiens'; (2) ἂν ᾖ θέλουσα (Soph.) "whatever she wants"; (3) οὐδέ τις ἔστιν ἀρὴν καὶ λοιγὸν ἀμῦναι (Homer) "nor is there any one to [= shall, can any one] keep off curse and ruin"; (4) ἀλλά τις εἴη εἰπεῖν (Homer) "but let some one go-to-tell" [= tell]; (5) βῆ φεύγων (Homer) "he took flight" in contrast with βῆ δὲ θέειν "he started to run"; (6)

ἤιε ταύτην αἰνέων διὰ παντός (Hdt.) “he always praised her (he went on praising her)”.

3. Corresponding Sanskrit examples, chiefly from Whitney's Grammar 1075, are: (1) *parikrī́ḍanta āsan* (MS.) “they were playing about”; (2) *syantsyánt syā́t* “may be about to drive”; (3) *çṛṇván tiṣṭhasi* (RV.) ‘audiens stas’; (4) *prativāvadato ’tiṣṭhan* (Āit. Br.) “kept vehemently refusing”; (5) *vibhā́jann éti* (RV.) “he ever gives away”; (6) *agnir . . dahann āit* (PB.) “Agni kept burning”; (7) *parājitā yanto* (TB.; = devicti euntes) “getting beaten”; (8) *ghnantaç caranti* (PB.; = caedentes eunt) “they make a practice of beating”.

4. The Avesta has particularly instructive examples for the infinitive complexes with ‘esse’ and ‘ire’. I have extracted the following from Bartholomae Wbch. 271 m, for *asti* ‘est’; (1) *θwōi ahī* = tueri es (in‿tuendo es), with the sense of beas rather than defendis; (2) *vōi ahī* = gaudere es, i. e. delectas; (3) *kāθe aŋhat̰* = amare erit, amabit; (4) *nōit̰ hāu ās vaoze* = neque ille erat (for est) vehere, i. e. non vehit; (5) *asti bərəθe* (959) = est ferendo (cf. est solvendo), i. e. ‘potitur, possidet’. Note with the locative of nouns (6) OPers. *ašnaiy āham* = in progressione eram, i. e. “I was marching”; (7) Av. *ahmī θwahmī-vīčiθōi* (Y. 32, 8) = “sum in tua secretione”, i. e. “werde ich von dir geschieden werden”; (8) *yat̰ usnąm aēiti vaēδya* (Y. 10, 13) = si voluntatum it in‿adipiscendo, i. e. adipiscitur. For the root *ay*, as in the last example, but rather with the sense of ‘versari’, we have (9) *aēni bərəθi* = eam (i. e. ibo) ferre (“ich will künftig hervorbringen”). Note further for ‘stare’ (1601, 2) (10) *tē hištənti γžarə·γžarəntīš* = “illae‿res stant fluc-fluctuantes” (cf. § 3, 4).

Ellipsis in analytical complexes.

5. The ellipsis of the leading verb, when a mere copula, is admissible for all numbers and persons. In the Sanskrit periphrastic future (v. Whitney § 944) it is the rule to write the agent noun alone in the singular, dual, plural for the third persons (i. e. *dātā́, dātā́rāu, dātā́ras*), but to express the 1st and 2d persons of all the numbers by the singular noun welded with the appropriate forms of the copula (i. e. sg. *dātā⁀smi ⁀si*, pl. *⁀smas ⁀stha*). But the ellipsis sometimes affects the 1st and 2d persons, and dual and plural forms of the noun prius are sometimes employed in those persons. Barring the time note, the future connotation, *auctor sum es est, auctores sumus estis sunt* represent a formation identical with the

Sanskrit future periphrastic.[1] If Horace *C.* 1. 9. 21, nunc et latentis proditor intimo/gratus puellae risus ab angulo, were Vedic prose, we should not need to trouble, as the Horatian annotators needs must, over zeugma in *proditor* (Skr. *pradātā*[*r*]), for it would carry *est* (or *sit*) with it, making *proditor* = *prodat.*

6. Another ellipsis to which attention may be called at the beginning is that of the copula with the infinitive in Sanskrit, e. g. *nákīm índro níkartave* "Indra is not to be put down" (Whitney § 982 c). The Latin historical infinitive is no doubt analogous, and it becomes an open question whether the 2d pl. pass. *agimini* is not the infinitive rather than the participle (sc. *estis*).

The REX⁀ERO *forms* (*relatively late IE.*)

7. In the Rig Veda we have recorded forms not a few centuries closer to the proethnic speech than any other forms of record, and that system of verbal flexion now generally known as the injunctive there has the value of past and present narrative tenses, and of subjunctives and optatives, which are the emotional forms of verbal utterance (35). After the Rig Veda there was a gradual elimination of such timelessness and moodlessness in the injunctive system. This injunctive flux was also represented (?), as Professor Bloomfield has pointed out in AJPh. 33, 1 sq., in a different sort of moodlessness: "As far as earliest Hindu speech is concerned, ideas which are expressed in a given mood may be, and are, on a large and surprising scale, expressed equally well in another mood, the circumstances under which the two statements are made being precisely the same". Especially note the interchange of the future with the subjunctive, imperative, precative (v. exx. l. c. 29; Speyer Ved. u. Skr. Syntax 183, where the subjunctive is pronounced the most usual form of the future in the mantra or song parts of the Vedas). In Latin, *erit* and all the *-am* 1st persons are now explained as original subjunctives. Accordingly, in the exposition of the injunctive forms to follow I shall deem it expedient to waste no further words when I present promiscuously forms classified as presents, futures, aorists, subjunctives; nor shall I specially remark on the occasional middle forms included among the actives.

8. And now, to plunge abruptly, I propose to study forms of the

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[1] The Latin combination *auctor est* (cf. Umbr. *uhtur* 'magistratus collegii cuiusdam') belongs with Av. *aog* 'praedicare' (Bartholomae Wbch. 37) and not, as Prellwitz correctly sees, directly to *εὔχομαι*.

rex⁀ero type on the supposition that *rex⁀*[1] is, or was, a rootnoun in the nominative, while *⁀ero* is identical with Latin *ero eris erit*, original paradigm ESO ESES(I) ESET(I), etc.

9. This assumes that the rootnoun *rēx* was participial enough in its nature to govern the accusative, i. e. was a transitive noun. I note Vergil's populum late *regem*, where *regem* = dominantem; also cf. in Horace (cited in § 5) *proditor* = *prodens*. Examples of transitive rootnouns in composition in the Rig Veda are *áhiṁ apáḥ pariṣṭhā́m* = draconem aquas circumstantem; *yáṁ yajñáṁ paribhū́r ási* = quod sacrum circumstans es. Similar accusative regimen with nouns adjective, e. g. *gnarures*[2] *esse hanc rem* (Plautus, Mo. 100), and substantive (v. exx. in Riemann et Goelzer Gram. Comp. du Grec et du Latin, Syntaxe, §§ 53–54) is not so rare. An intransitive prius in *lux⁀erit*.

10. The conviction must have been forced on all who have dealt studiously with the Sanskrit and Avestan vocabularies that the monosyllabic and rootnouns are remnants of a formation of very much wider extent; and the conclusion will not be remote that these rootnouns are, in fact, nominally inflected roots. On the general instability of the monosyllable cf. Wackernagel in IF. Anz. 24, 114. Be it noted that these nouns occur with the *ĕ* and *ŏ* vocalism and, under conditions, in the zero grade also; and function both as action and agent nouns, as infinitivals and participials, e. g. in Latin *nĕc-s* (action) and *au-spĕc-s* (agent), *rēg-s* (agent); in *Ϝόπ-ς*: Lat. *vōc-s* (action), *κλώπ-ς* 'thief' (agent). It should be further noted, apropos of Skr. *pā̆d*[*s*] 'foot', acc. *pā̆d-am*: Lat. *pē*[*d*]-*s*, acc. *pĕdem*, that the long and short vowels might vary in the same paradigm. In Lat. *dŭx* 'leader' we have the weakest vocalism, while in *Diēs* (*⁀piter*): Skr. *dyāúś* we have a vriddhied diphthong. Any of these grades might have entered into the injunctive flexion, but the *ŏ* grades are found only in other complexes (56, 59).

11. No justified objection to the complex *rēx⁀ero* can arise in the singular forms, unless the objector is prepared to object to Horatian sive *reges* | sive inopes *erimus* coloni. Against *rex⁀erimus* an objection would lie and, in spite of Skr. *dātā́ 'smas* (5), it may be asked why not **rēges⁀erimus* or, with haplologic re-

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[1] By using the tie or bind in these forms I seek to indicate that though tending to a restricted order the complexes long remained separable (57). Used as in *in‿accipiendo* (§ 4) the tie indicates the locative of the original Avestan.

[2] I explain *gnarures*, with an abnormal *-ā-*, as a pf. ptc., dissimilated from **gnānuses* : Skr. *vij*[*n*]*ānúṣas* (g. sg.) 'gnaruris'; see on Umbr. *covortuso*, 74, 92.

duction, **regerimus*. One may wonder if this state of things has survived in *legerimus*: *intellexerimus*, the *lex*⁀ forms representing the predominance of the singular type, the *leg*⁀ forms of the plural, under the influence, of course, of pf. *legit*.

12. The shortening assumed for **reges*⁀[*es*]*omos* fulfilled itself in Latin for some singulars, e. g. in the short future (perfects) *capsit*, *rapsit*, *clepsit* (old formula in Livy, 22, 10, 5), from **caps*⁀*e*[*se*]*t*, etc. Particularly note that the -*s*⁀*ero* futures occur chiefly in verbs entitled to rootnouns with a nominative in -*s*. In liquid verbs, forms like *verrerit*, *vellerit*, *volserit* (see Neue Formenlehre 3, pp. 411, 419) may contain, however, a nominatival -*s* under the conditions pointed out below (17) for the Greek aorists. The pf. *lucs*⁀[*es*]*it* will have been the haplological form of *lucs*⁀*erit* (9).

13. The conditions assumed for futures like *capsit*, *facsit*, *clepsit* are exactly fulfilled in Sanskrit in the *sa* aorist, where the curious limitation obtains that *sa* is only attached to roots where the resultant group yields *kṣ*, as in *dukṣas*[1] 'mulgeas', from *dukṣ*⁀*a*[*sa*]*s*, wherein the prius *dukṣ*⁀ is earlier than the Sanskrit reduction of all double consonant finals.

14. In Greek there were two treatments of the combination DĒIKS⁀ESO: 1st with haplology, δείξ-ω; 2d without it, the δειξ-έω type. Note the different gradation of the noun prius in δείξω as compared with Skr. *dikṣás*. In Latin *dūxero*, if the quantity is certain, while we may have a vriddhied nominative older than *dŭx*, we may rather have to recognize the influence of the present *douco*.

15. Why, in all these forms, did the singular *rēx* oust the plural *rēges*? In the light of the Sanskrit periphrastic future (5) the fact is clear enough; but later on, when we come to the present system, we shall see the occasional survival of the plural ending and its intrusion—as perhaps in *legero* : *intellexero* (11)—into the singular.

16. There was one class of rootnouns, involving the commonest stems, wherein IE. n. sg. and pl. were alike, viz.: in the compounds of roots in long vowels, cf. Homeric καταβής⁀[εσ]εται,[2] μεταστής⁀[εσ]ω, ἀναστής⁀[εσ]ουσιν, καταθήσω, ἐπιθήσομεν, παραθήσομεν. Typically, of course, these plurals in -ης are pre-Greek, and the intervocalic σ has always been explained by the analogy of the κλέψω type, but the explan-

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[1] A connection with Latin *ducere ubera* is scarce to be doubted.

[2] By writing interior ϛ in a Greek form I indicate the phonetic phenomenon symbolized in § 1 by -*ss*. Note alongside of welded complexes like καταβήϛ⁀εται an instance like *tvám hí ratnadhā́ ási* (RV. 1, 15, 3), wherein °*dhās*⁀*asi* remained separable.

ation from $-s^s$ may rather be the correct one. All that this means is that θήσ-ω was the syllabification employed. For a noun prius of this type note the relatively perfect equation between Skr. *dās⁀athaḥ* (RV. 8, 10, 1) and δώς⁀ετον. In the Sanskrit form, as I remark in advance, *th* is either haplological for *sth* (80, 82) or has arisen according to § 77 (cf. 75, 80–81).

17. In the liquid verbs Greek has clearly preserved traces of the complexes with ⁀ESO. In Homeric μενέω 'manebo', if μεν⁀ is not a neuter (69)—or a suffixless locative infinitive (38)—it may have been brought over from the plural μεν[ες]⁀έ(σ)ουσι (but see 15). Even the weakest grade (10) appears in the prius in κατα-κταν-έουσι (Z 409) and κατα-κταν-έεσθε (Ξ 481), wherein -κταν- is in the vowel stage of *dikṣ⁀* in Skr. *dikṣás* (14). The fact that the complexes long remained separable (57) is reflected in the unaugmented aorist ἄγειρα ἄγειρεν, wherein ἀγειρ⁀ is from a secondary (or original?) nominative *αγερς like χείρ 'hand' from *χερς. Thus we account for the difference between the futures like ἀγγελ[ες]⁀έ(σ)ουσι and the aorists like ἤγγειλε from ἀγγελς⁀[εσ]ε.

18. Nor was the rootnoun the only prius employed. In ψευδήσω (: ψεύδω) we have the agent noun ψευδής + [εσ]ω, and μελήσουσιν (δ'ἐμοὶ ἵπποι) will contain the prius *μελης 'cura' (v. Cic. Att. 10, 7, 4 navalis apparatus ei semper antiquissima *cura* fuit). For *μελης cf. Lat. *labos honos* (with a different vocalism) and the Sanskrit masculines *bhiyás-* 'timor', *jarás-* 'senectus' (nomm. non lectis). The aorist type ἐψεύδης⁀[ησ]α—cf. also ἐμαρτύρ⁀ησα from μάρτυρ, a most clear agent noun (88–89)—may contain a posterius ĒSA: Skr. pf. *āsa*, employed solely to form periphrastic perfects. [On ζῆτήσ-ω ἐζήτησα see § 59.]

19. These perfects have an apparent accusative in *-ām* as a prius, followed by *cakāra* 'feci', *āsa* 'fui', *babhūva* 'fui'. Morphologically this form in *-ām* is a samdhi form for *-ān*, nom. sg. of a participle (-ων). The prevalence of the samdhi form proper only before the infrequent form *babhūva* would have been due to mistaking the *-n̄* form before *cakāra* for an accusative. The original participle with *cakāra* is justified by a Greek case like εὖ γ' ἐποιήσας ἀναμνήσας με = bene me monuisti (Plato), cf. οἶον . . ποίεις ἡγούμενος (Ch. 166 C.) = what, do you think? Note the Skr. gen. pll. in *ān* (not *ām*) mentioned by Macdonnell Vedic Syntax p. 262 a, and cf. KZ. 20. 219.

20. If we had in Sanskrit the injunctive corresponding to *rexero* it would fall into the *s* aorist, 1st sg. *rākṣam*, i. e. *rāks⁀[as]am*, and in Rig Veda its 2d and 3d sg. would have been **rākṣ*, i. e. *rāṭ*,

with entire ellipsis of ⌒*asas* ⌒*asat.* Now it happens that we actually do find *rāṭ* in injunctive function in RV. 6, 12, 1, where Ludwig's proposal to render it by "soll herrschen" (RV. IV, 354) met the approval of Böhtlingk in PW.^{2}, s. v. *rāj*: "wohl verbum fin. und der accent zu tilgen". Macdonnell l. c. § 452 cites *rāṭ* as a "present injunctive". Other forms of the same type are *yāṭ* 'sacres, celebres', *a-vāṭ* 'vexisti', *vāṭ* (YV.) 'vexit'.

21. Perhaps the commonest form of this type in RV. is *adyāut* (2d sg. 1°; 3d sg. 14°; cf. *dyāut* 3d sg. 1°). This verb form belongs with the noun *dyāús* 'dies', and it may be that after a fashion common in Sanskrit of adjusting *-s* and *-t* to the 2d and 3d persons *-t* is for *-s*. Besides, as a 2d and 3d sg., *dyāús* would have tended towards **dyāúṭ* (cf. Whitney 226 d). It was perhaps from this single form *dyāut* that *-t* firmly attached itself to the root DYU, otherwise attested only in the noun *dyāús* and its case forms. The diphthong type of the 1st sg. **dyāuṣam* is found in θευς^[εσ]ομαι 'curram'.

22. The omission of the copula with the form *rā̆ṭ* is precisely what habitually took place in the future *dātā̆*, and I do not feel that *rā̆ṭ* need go accentless any more than 3d sg. *dātā̆* (see § 5, and on the Vedic forerunners of the *dātā̆* flexion cf. Whitney 946).

The Sanskrit sigmatic aorists; the pluperfect.

23. In the Sanskrit development of the paradigm of the *s* aorist the noun prius in the singular seems to have pervaded the dual and plural, and some of these injunctive forms look clearly to have imperative forms of *as* 'esse' in the complex, e. g., to use Whitney's paradigm, 2d and 3d dual *a-nāiṣ-(s)tām*, 2d plural *a-nāiṣ-(s)ta*.

24. But what are the 2d and 3d sg. endings *-īs -īt* found in the other Vedas for these *s* aorists? Though another origin is possible (59, 62) I suggest that they are identical with our Latin friends *sis sit* (33). Thus in AV. 10, 9, 7, *māibhyo* (= *mā ebhyo*) *bhāiṣīḥ* (= ne ab‿eis metuens‿sis), we have a negative turn exactly like the turn in *numquam istuc dixis neque animum induxis tuom* (Plautus Cp. 149). So, in spite of the absence of the -(*s*)*īs* forms from the Rig Veda, IE. forerunners seem certain.

25. The Sanskrit *iṣ* aorists are of slightly different formation, though their 2d and 3d persons in *-īs -īt* may really belong to the type of *bhāiṣīs*, having spread from roots in *-s*, as e. g. *moṣ*^(*s*)*īs* 'rapsis', *rakṣ*^(*s*)*īs* 'defendas', *hiṁs*^(*s*)*īs* *hiṁs*^(*s*)*īt* 'noceas

noceat', *dās^(s)īt* 'vastet'. In *vadhi-ṣṭa* 'caedatis' *-ṣṭa* is the imperative = 'este' (23), preceded by a locative infinitive in *-i* (37). Another possibility to mention, especially in view of the vocalic difference between Skr. *á-vediṣam* and ᾔδεα, is that an agent noun in *-is*—cf. the transitive noun in -τις in μάντις ἦσθα τάδε (Eur.)—say WĔIDIS 'sciens', combined with [ĔS]E yielded a Skr. 1st sg. *a-vedis^[as]am*, but a Greek ᾔδ[ις]^ε(σ)α. The intransitive nouns in *-is*, often reduplicated, were rather common in the Vedas (Whitney 270 f.). Lat. *dedissēs* (*ss* from *-s*^{s}, §1) contains DEDIS^ = Skr. *dadis* (transitive, see Whitney 271 f.) + *-ēs* as in *amarēs* (61), while *dederat* comes from *ded*[*is*]^*esāt.*

The ESK̂O/ISK̂O *complexes.*

26. This explanation of *avediṣam* leads me to insert, somewhat out of its due order, the explanation of the Greek verbs in -ίσκω. Thus εὑρίσκω is from *εὑρις^[εσ]κω; δόσκον = δος^ (82) + [εσ]κον; in ἔ-βασκε 'went', φάσκε 'said' the priora were βας^ and φας^, these shortened forms being comparable with δος^ (: δίδωμι). So Skr. *gácchati* 'goes' will be from G^{w}A^{x}S^[ES]K̂ETI;[1] cf. also Lat. *pās^*[*es*]*cor*. On the relation of ESK̂O : EIMI see § 52.

27. We should perhaps also admit into our calculations -ISK̂E-, from the root EI, in which case we shall have an explanation of Lat. *pro-ficīscor*, from the infinitive *pro-ficī* (like *interficī*) + *iscor*; cf. *pacī^(i)scor* 'ad‿pacendum eo'. So in Aeolic θναί-σκω we have a dative prius θνᾳ^ (from *g hnā-* 'nex' : Skr. *han* 'necare' : : Skr. *vrā-* 'troop' : *var* 'surround', cf. Macdonnell l. c. 367; or like Av. *vōi*, see § 4) + (I)SK̂Ō. The future θανοῦμαι is like κτανέομαι (17). Of course εὑρίσκω (26) admits of the division εὑρ-ίσκω, but note its future εὑρής-ω (cf. 18 and 25). I do not overlook that this analysis of the ISK̂Ō and ESK̂Ō forms assumes a greater antiquity for these simplices than for the SKO-verbs in general (52). In leaving the group it is well to note that the type of Lat. *crudescit* comes from *crud*[*os*]^*escit*, while *vesperascit* is contracted (? procope) from *vespera^(e)scit.* Note *lūc*[*os^*]*escit*, prius = λευκός 'clarus'.

Sanskrit desideratives.

28. With the injunctives belong the Sanskrit desideratives, based on reduplicated agent nouns, e. g. 3d sg. *cikits^*[*as*]*at* 'se‿monstrans‿erat', *pipas^*[*as*]*ati* 'bibens‿est', whence 'bibere vult'.

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[1] On Skr. *a*^{x}, not *ə* (Skr. *i*), in the form *gácchati* note *bhananti* (RV.) (= *fantur*) : *fātur* : : Lat. *danunt* : ἔ-δω-κα (70–71).

Genitive regimen due to composition with substantive.

29. The syntactical consequences of the above explanation remain yet to be drawn. In RV. 6, 12, 1, *rāṭ* 'rex esto' (20) governs a genitive *barhiṣaḥ* 'sacrae herbae' (quasi 'pulvini'). This means that *rāṭ* still had its noun regimen, cf. cases like Skr. *jétā dhánāni* 'vincens bona' in contrast with *jétā jánānām*[1] 'victor gentium'. Thus we learn to interpret the genitive with fut. βασιλεύς͡[εσ]ω as due to the noun prius, while a dative was the case of possession with the copula in the posterius.

The non-thematic optative was a subjunctive.

30. It seems never to have occurred to anybody to ponder the origin of the optative type of Skr. *syā́t* : Lat. *siet*. There is a condition of growth in animals when we call them hidebound, cf. ἐχεδερμία. Similarly trees are sometimes barkbound. We scientific mortals are very apt so to be bound by our classifications as not to be able to peer through the meshes of our own schematisms. I suffer thus constantly myself. The term optative (εὐκτική) has bound us thus and we have long lain under the spell of that nomenclature.

31. What is *syāt*: *siet*? Waiving questions of chronology not yet within our scrutiny, IE. *s(i)yēt* is a long vowel subjunctive of the root ES in its weakest stage of S (perhaps in the last resort a procope product; cf. Lat. *'s 'st*) as inflected after the (I)YE present system. This mode of flexion ranged widely (v. exx. in Brugmann Gr.[1] 2, 2, §§ 705–727) and to deny it to the root ES were wholly unwarranted, unless it could be shown that the (I)YE conjugation and the long-vowel subjunctive arose in IE. flexion after the so-called non-thematic optative had crystallized.

32. This subjunctive in (I)YĒ had undoubtedly been segregated and allocated to special use proethnically; and secondary endings, starting with the 2d and 3d sg. where the subjunctive had -SI/-S -TI/-T, had been given to the entire optative paradigm, which demonstrably ran as follows:

Sg. 1 (E)S(I)YĒ-M 2 (E)S(I)YĒ-S 3 (E)S(I)YĒ-T
Pl. 1 (E)S(I)YĒ-MOS 2 (E)S(I)YĒ-TE 3 (E)S(I)YĒNT[2]

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[1] Note that here the accent of the first *jétā* (transitive noun), which I take to be of diacritic purport, adheres also to *jétā* with genitive.

[2] By writing (E)S(I)YĒM, etc., I mean to indicate that the initial E of *εἶεν*, e. g., is just as likely to be of IE. provenance as to be due to an ethnic analogy. I hold that Hom. *εἶεν* is the normal Greek descendant of (E)S(I)YĒNT, and so is Lat. *sient*, Osc. *o-siin*[*ns* (see Buck Elem. Buch § 195). Surely Lat. *estis* Lith. *ẽste*

33. In this paradigm neither the Greek nor the Sanskrit forms give any warrant for the reduction of optatival YĒ to Ī, and there was, under normal conditions for the subjunctive active, no accentual shift to produce reduced vocalism. There was such a shift in the middle, and we have Skr. 1st sg. act. *açyā́m* (for phonetically rigorous **çyām*) 'adipiscar': 1st pl. mid. *açī-máhi* 'adipiscamur' (but see 34). How these conditions could have affected the paradigm of ESIYĒM, even though ἔσομαι is a middle future, I do not see; yet Lat. *simus sitis*, Umbr. *sir si sei*, OHG. *sis* seem to certify the reduced forms. For the active optative of ES, however, I am prone to believe that I came in from compound forms or enclitic uses of -SYĒS -SYĒT (see Kretschmer as cited below, 59).

Present suffix (I)YE : EI *'ire'*.

34. After the exposition further along (44 sq.) of the rôle of the root EI 'ire' in forming verb complexes it will become clear that the present formant IYE is a present stem of EI. Thus in Skr. *açīmáhi*, e.g., we have an infinitive **açī̆* (37)+*īmahi* (RV.)=imus; in *duhītá* 'mulgeat' a complex *duhi* = ad‿mulgendum + Ī̆TO 'eat'. For *aç(i)yā́t* 'capiat' the possibility must also be weighed that the prius was *aç*, an agent noun nominative prior to the adoption of -s in that case (cf. 104–105); or that, taking **açī̆* for the prius, the posterius was *-yāt*: Skr. *yā* 'ire'.

Moods of emotional origin: mood syntax.

35. It can be no accident, however the resolutely but mistakenly pragmatical have cried pooh-pooh, that the emotional verb forms, the subjunctive and optative, of our mother-speech are characterized by long vocalism which admits of the tremolo, and by diphthongs, at least concomitant with—as in Sicily (see Schneegans, ap. Meyer-Lübke Ital. Gram. 35; Wechssler Gibt's Lautges. 131) they have been shown to be the result of—passionate utterance. Language, we keep forgetting, is speech; and mood—I mean temper—distinctions obtain to-day universally; and in English we still, for we

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Greek ἐστὲ have a proethnic E-, in spite of the greater regularization of the Indo-Iranian paradigms in regard of the distribution of the strong and weak root forms. Likewise Lat. *sumus* comes to its rights when we combine it with *erimus*, both from a startform (E)SOMOS; and the total loss of the initial E- would be due to the generalization of cases of procope to which this enclitic verb was liable, as e. g. in Lat. *tectumst tectust tectu's* (cf. Eng. *that's*). Thus Lat. *sunt* and *erunt*, Skr. *sánti* are all to be derived from (E)SONTI, with O by deflection in the syllable after the accent. On the 3d pl. (S)ENTI see § 51. In the Gothic 2d pl. *siyaip* we have a contamination of non-thematic SIYẸ̄TE by the thematic ESOITE (cf. ἔοι 'siet').

are still an Indo-European folk, indicate them by tone of voice. On the printed page only the context, the little emotional words accompanying (see Morris Principles and Methods in Syntax 45 sq.), reveals the feeling, and the "mood" does not reside primarily in the objective form of the word.

36. For genuinely historical syntax no very momentous consequences flow from the demonstration that the "optative" is merely a "subjunctive" allocated to special function. It merely shifts to the proethnic period the actual problem of Latin *siet*, viz.: that it is a "subjunctive" as well as an "optative"—and originally neither, but a complex with prior infinitive, in which ·(I)YĒT meant "goes", the whole used as a present future desiderative (see 63–65). Professor Bloomfield has lately shown (7) how little modal distinctions meant in hieratic Sanskrit, and I have elsewhere noted (Cl. Quart. 5, 190) that by reverting, after the manner of speaking, to the IE. period we sometimes do not bring ourselves sensibly nearer to syntactical origins than when we ponder on the phenomena, say, of Latin syntax. I have never believed that tenable distinctions can be drawn between future subjunctive optative imperative. The Sanskrit injunctives unite all these functions and exhibit aorist, i. e. narrative, functions besides, thus retaining and reflecting conditions prior to the allocation of special mood values to special objective forms. Our English imperative *come* is an optative when we sing "Come thou almighty king"; it is a something milder, a reverential, a precative, in "Come, Holy Spirit, heavenly dove"; it is still something short of an imperative in "Come, ye disconsolate", or even in "Come to dinner"; but in "Come at once, I tell you", it is imperious. Note conversely 2d sg. opt. *immais* = impv. cape in Old Prussian.

The Sanskrit future in -(i)şyáti.

37. In Skr. *naçi-şyáti* 'peribit' (= ad‿necem est) *hani-şyáti* 'necabit' (= ad‿caedem est; note the different voice that arises from taking the infinitival prius as active or passive) I interpret *-syáti* as pres. indicative to *syā́t*, original pres. "subjunctive". The prius *naçi*, here infinitivally employed, is absolutely identical with the Latin locative *nec-e*, and the complex = 'im‿sterben ist'. The Vedic infinitives in *-i*, though not very numerously recorded, are perfectly certain (cf. Macdonnell l. c. § 578). There is little, and I rather think no, formal justification (pace Brugmann op. cit. § 749) for interpreting the *i* of *naçisyáti* as from *ə*. Still an agent noun prius might be admitted, or an ES infinitive—suffixless locative (50).

Thus θεν-έει 'feriet', the thematic diphthong (55) apart, may be from G^{w}HENES-(S)YÉTI or from G^{w}HENE[SI]-SYÉTI, cf. Skr. *aviṣyáti* where, as in *avediṣam* (25), the haplology affected a different one of the like syllables.

38. But we come out most simply with θεν-έει when we set down θεν as a suffixless locative (for the interpretation of which see § 50) + -ι(υ)ει, which is the Greek correspondent of Lat. *erit*. By good fortune the Rig Veda has preserved evidence of this formation *in tmesi*, in the words (1, 120, 7):

> yuváṁ hy *ā́stam* (dual) mahó *rán*[1]
> vos enim *eratis* magnum *donare*
> "ihr *wart* bestimmt grosses *zu spenden*" (Ludwig, followed by Griffith).

Here *rán* is an infinitive from the root *rā* 'dare', and we have in the context (1, 120, 6*c*) a precise counterpart in *dán* from the synonym root *dā*, viz.: in the words

> *ā́'kṣī* çubhas patī *dán*[2]
> huc oculos, splendoris compotes (dual), *date*
> dasz ihr, herren des glanzes, hieher die augen *richtet* (Ludwig).

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[1] The Vedic commentator Sāyana did not know what part of speech *rán* was, but he knew its meaning perfectly; see PW.^{2} s. v. *rán*.

[2] The Sanskrit root *dan* set up in the Petersburg lexica (PW.^{1} III, 507) on the basis of two Rig Veda passages does not exist. The passages are:

1, 174, 2*a*, *dáno viça indra mṛdhrdvācaḥ*,

where Ludwig renders *dánas* by *tötetest*, Grassmann by *straftest*, Griffith by *humbledst*. The pada ought to be rendered by

dedisti <in fugam> vicos (= hostes), Indra, maledicentes;

cf. Bell. Gall. 5, 51 Caesar . . celeriter hostes in fugam *dat*, Phaedrus 1, 22, 9 improbam <mustelam> leto *dedit*. There is a kindred use of δίδωμι (Liddell and Scott s. v. II), of the giving over of an enemy to dogs (κυσίν), fire (πυρί), blows (πληγαῖς). The ellipsis of something to correspond to 'in fugam' in the Rig Veda will be implicated with the rare NO flexion (cf. Lat. *danunt*, 70). [Cf. Eng. give *it* to one = beat.] In the other passage we have *dán* already correctly taken by Ludwig, whose rendering is "zu spenden":

10, 61, 20c: *ūrdhvā́ yác chréṇir ná çíçur dán* <*? makṣú*>
recto quod collegio similis puer <rectus est> in‿dando (= recte dat) <? celeriter>
d: *makṣū́ sthirám çevṛdhám sūta mātā́*
celeriter firmum bona‿augentem peperit mater.

Apropos of my rendering of *çréṇis* by 'collegium', it is at least more intelligible than the usual 'linea'. I really prefer to follow one of the best native glossaries, the *Trikāṇḍaçeṣa*, and render by *seva-pātra-m* quasi 'bucket', but perhaps originally 'well-sweep' (: the root of Lat. *clino*), from its inclination. Then *ūrdhvā́ çréṇis* would be the upraised and dripping bucket, fit symbol for the generosity of Agni. For purposes of completeness I add that of the four

Here the imperatival infinitive *dán* (cf. δι-δόν-αι) = Av. *dąn* in Y. 47, 1, where Geldner renders *ahmāi dąn* by *verleihe uns* (see Wolff Infin. d. Ind. und Iran. I, 93); and *dąm* in Y. 44, 16, where Geldner (KZ. 28, 206) renders by 'zu geben', Bartholomae by 'zu bestimmen' (Wolff, 91). Against the interpretation by '*domūs*'[2] (with the awkward pair of genitives), it should be observed that *akṣí dán* seems very similar to *çrad-dhé* (infin.) = *credere* (i. e. cor dare). Cf. also Eng. 'to give ear'. Lat. *audi* (impv.) is from *aus-d(h)a*^{x}*i*[1] (infin.), *audībit* from *audi⁀ibit* or *audi⁀fit*, *audīvi* from *audī⁀ivi* (cf. 66).

39. To take up the other Sanskrit futures, in *vartsyáti* 'vertet' we probably have a reduction of WERT-I-, a locative prius before -SYETI—unless one chooses to believe that the IE. reduction of a diphthong or absorption of a short vowel before the accent (see § 1, 3) had ceased to exist before these complexes came into existence; or to insist that the difference between the *naçisyáti* and *vartsyáti* types cannot be the result of recomposition. In the *dāsyáti* 'dabit' type the prius was either *dā(i)*⁀ (cf. Av. *vōi*, § 4), or *dāsi*⁀, identical in formation with Lat. *fā-re* (impv. from infin.) and closely related to *dāre*. Be it noted in passing that Lat. *fāre* attests, out of Sanskrit, the Vedic imperatives in *-si*, e. g. *rāsi* 'da', *yā-si* 'i' (cf. Whitney § 620). In narrative, *fāre* arose by ellipsis from *bhāsi⁀asi* (6), cf. Lat. *sequere*.

The Latin -BO *futures*; *the conative imperfect.*

40. There is no reason to suppose that the NEḰI-SYÉTI futures were not liable to tmesis in IE. times; nor that they are any more original than the Latin *bo-* futures. They survived a little more widely, that is all. Were the *-bo* complexes left on the western frontiers (Gaul, Italy) as the race moved east, or did they represent a westward wave of extension? The condition of rivalry between *kar as bhū* in forming the Sanskrit periphrastic perfect (19) may have obtained as well proethnically between ES and BHŪ in forming

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cases of *patír dán* given in PW.[1] III 507 s. v. 1 *dan* Griffith (after Ludwig) seems to do full justice to 1, 149, 1*a* and 10, 105, 2*d* by a rendering equivalent to 'dare' (dandi); and for 1, 153, 4*c* his rendering = Lat. det. In 10, 99, 6*a* his rendering of *dán* = superavit. This means that there *dán*, with ellipsis of something like *āsīd*, means gave it to, cf. on *dánas* in 1, 174, 2a.

[1] This is not contradicted by *ob-oedio*, wherein, in the passage of post-accentual *au* to *ū* (or plebeian *o*), the influence of the preceding labial *b* and of the succeeding dento-palatal articulation of *di* (cf. *ac-ci-pi-o* : *oc-cu-pa-re*) resulted in a palatalized *ō*, cf. *Cloetemestra* (Stolz Lat. Gram.[4] 79) with *oe* from *ŭ* under very like conditions. See also Marouzeau in Mém. Soc. d. Ling. 17, 272.

periphrastic futures. But all questions of this sort aside, I find in Latin *ad-stabo*—which will serve as a type for the 1st conjugation—a prius **ad-sthāi* like Skr. *vi-khyā́i pra-khyā́i* (omitted in Macdonnell's list, § 584) = 'ad‿dis-(pro-)spiciendum'; and in *acciēbo*—typical for the 2d conjugation—(with *ē*, from EI or AI, *in hiatu*) a prius like Skr. *pra-mīye* 'ad‿diminuendum' (cf. however the Avestan infinitives in long diphthong, 4). OLat. *scībit* (4th conj.), if we reckon with vowel levelling and the pre-Latin initial stress, may be phonetically just as normal as *ácciēbit*. But a startform SCIYI (locative like Skr. *dṛç-ī budh-ī*) is also permissible. The *ī* in *audībit*, another 4th conjugation form, has been explained above (38). Forms like *scibo*, *ibo*, *audibo*, as exceptions to prevailing modes—and it is always the exceptional form that is likely to prove original—are old, and Skutsch's derivation of the *-bo* future from *amans⌒bo*, etc. fails precisely, save by invoking an improbable analogy, to account for these *-ībo* forms. For the sense, in view of our own periphrasis "I was[1] loving", no English speaker would be reluctant to follow Skutsch, but in my opinion, "I was for loving" better accounts for the more "modal" uses of *amabam*. I have in mind such cases as Terence Phormio 298 qua ratione inopem potius *ducebat* domum, wherein Professor Bennett (Syntax of Early Latin p. 35, 6) renders the verb by "was proposing to bring", which is merely "was for bringing" writ large.

41. Here I do not fail to anticipate the objection that the same mode of translation is valid for the uncompounded Greek imperfect. Thus Professor Gildersleeve (Syntax Class. Greek I, § 213) renders ἦγες in Plato, Phaedo 230 A by "you were going to take". This raises the question why Latin came to give up—did it ever develop?—the thematic imperfect in favor of the periphrasis with *-bat*; and one part of the answer will be that the periphrasis with *-bat* had the value of making quite precise that aspect of the original imperfect represented confusedly in ἦγες [but not in ἄγεις, see § 63], but quite clearly in *duce⌒bat*, so long as its parts, felt as "was for leading", were still several in the domain of consciousness.

42. It has been pointed out often before that a complex like *amabat* exists in Old Bulgarian, wherein *vidě-achŭ* = videbam and *nesě-achŭ* = ferebam. The startform for *-achŭ* was *jachŭ* from IE. ĒSOM (cf. on ἐψεύδης⌒[ησ]ε 18). The prius *vidě-* is like *vidě́* 'to

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[1] With *was* cf. Skr. *mṛgayām* (*-m* for *-n*, 19) *avāsīt* = 'venans erat'. An IE. complex with the root WES 'habitare' (manere) gave rise, I now suspect, to the pf. ptc. type mentioned in §§ 72, 98. On the ptc. "suffix" -MENO- = 'manens' see AJPh. 31, 410[1].

find' (RV.) and contained a final -AI (-OI), but not -EI, unless -(*j*)*achu* had some effect not known to me on the preceding diphthong. But the infinitive in -EI (cf. Persson IF. 26, 25) seems amply to come to light in other forms we shall have to consider.

43. In 3d conjugation types like *tegēbam* the *ē* may, in a not yet welded final syllable before a labial -*b* (-*f*), actually be the normal phonetic product of -AI or -EI, I think. For *tegē⁀* from **tegai* cf. dative endings like *Diane Fortune* (v. exx. in Buecheler-Windekilde Lat. Dekl. § 265), and note *ē* from *αι* in the 2d syllable of Cloetemestra (38). Also note the old *ē* datives of, say, *Apollo* (v. Thes. Ling. Lat. II. 244, 25 sq.). As an iambic word **tegai* would have been liable, perhaps, to quite early assimilation to **tegei* and I even suspect that, thanks to the "iambic" law, words of the type of *humi* = *χαμ-αί* had their -AI reduced to -*ī* previous to any historic attest of Latin forms. But in **tegai*, and in a very large number of infinitives belonging to the 3d conjugation, there may have been a sort of vowel levelling that produced **tegē*(*i*), comparable with the harmony that saved the second vowel in the genitives *tegetis*, *segetis*, etc. In the isolated infinitive it was the type of *agei*/*agi* that prevailed. Be it added, apropos of *tegēbat*, that the derivation from **tegēs⁀bat* (see 18 on *ἐψεύδησε*) is also admissible.

Complexes with EIMI *and* ESMI.

44. I am now going to try to show that in the IE. flexion the *φέρ⁀εις* and Skr. *bhár⁀asi* types are compounds in which -*εις* = Lat. *is* 'goest' and -*asi* = Lat. *es* 'art'. But it is not necessary to affirm that -EIS meant 'goest' in any full sense, for it may have had a nearly copulative value like *πέλεις* (: Skr. *cárasi* 'erras'); and Bartholomae (Wbch. 147, 2) expressly defines *aēiti* by 'versatur'; cf. Horatian gratior *it* dies (C. 4, 5, 7). Perhaps Homeric *εἶς* (pace L. Meyer KZ. 9, 373) was copulative 'īs', not 'es'. In building up the complexes from which the conjugation forms derive I shall hold myself strictly to the forms of record for the conjugation of ESMI and EIMI. This will not prevent me from admitting as proethnic, rather than ethnic, types and analogies, forms that violate the (subsequent) distribution through the paradigm of the strong and weak root stages. Thus, as above (32 fn.) I treated the strong form in 2d plural *ἐστὲ* : Lat. *estis* Lith. *ẽste* as belonging to the mother-speech, so I shall now suppose, on the basis of Skr. *etas* (AV.) 'duo eunt', Lith. *e^{i}te* 'itis', Skr. *īmahi*, Lat. *īmus* (? or *eimus*), that EIMOS ĪMOS, as well as ĪMÓS, are equally valid proethnic forms.

Conjugated demonstratives.

45. The question will arise how, if EIMI and ESMI furnished the standard conjugation forms of the other verbs, they were themselves previously conjugated. This question I might prudently avoid, though it would be necessary in that case to plead that conjugation probably started in a few words and was afterwards extended. My own solution of the difficulty involved in the conjugation of EIMI and ESMI lies in the belief that they were conjugated demonstratives to start with. Into this discussion the reader who declines to look at questions of general linguistics may refuse to go, but I propose to make my statements touching the conjugation of the demonstratives entirely pragmatic, albeit for ESMI and EIMI glottogonic.

46. In the Latin of Plautus the compound demonstrative *hic* is 1st person, *iste* 2d, *ille* 3d. In Greek, ὅδε = *hic*, οὗτος approximates *iste*, ἐκεῖνος = *ille*. Note Skr. *eşá-*, a compound of *sá-*, both being used with the 1st and 2d person pronouns, and *eşá-* inclining to *iste* as the demonstrative *iyám*[1] to *hic* (cf. Speyer l. c. § 131), *asāú* to *ille*. We come still nearer to my conception of ESMI in Ital. *ecco⁀mi* 'Here (there) me' (= I am), *ecco⁀lo* 'there it <is>', *ecco⁀ci* (*-ci* = Lat. *-ce*) 'ibi hi' = 'adsumus nos', *ecco⁀ne* (*-ne* from Lat. *unde*, cf. Meyer-Lübke Ital. Gram. § 370) 'adsumus nos'. The *ecco⁀lo* paradigm does not differ in essence from the '*dar he*' of a Southern darkey (see Fay in AJPh. 16, 20). With these IE. analogies before us, when we observe that in Hebrew the copulative verb *hū'* (originally = 'ille, is') is an adverb of a demonstrative value with verb endings (cf. Fay l. c. 19; Steinthal-Misteli's Abr. d. Sprachwiss. 2, 476), we cannot question the possibility of finding in EIMI (root EI/I as in Skr. *e-şá-*: Lat. *eyum* [acc.], weak stage in Lat. *is*, Skr. *iyám*, fem.) and in ESMI (cf. *es-*, nom., in the Oscan word *es-idum* 'idem') pronominal "roots" EI/I and ES. Note the Vedic use of *ayám* for "hier ist, sind" (Grassmann RV. Wbch. 207, 20).

47. What is conjugation? The indication of person in verb forms. Some languages conjugate their nouns, e. g. Hebrew (v. Bickell's Outlines §§ 103–104) and Namaqua (paradigms in Mém. Soc. Ling. 9, 308; reprinted in AJPh. 17, 353). Very completely illustrative of my conception of the conjugation of ESMI and EIMI is

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[1] In the stately, solemn periods of the Oration on Pompeius' military command (§ 55) Cicero uses *ii* (anaphoric of Nos, four lines before) as subject of *poteramus*; cf. Plautus Mc. 631, *ego* me credidi | homini docto rem mandare, *is* lapidi mando maxumo (further examples in Seyffert's Bericht über Plautus, Bursian, 80, 309).

the following Chinook paradigm extracted from Boas' grammar of that tongue in the Handbook of American Indian Languages, p. 618. Also cf. what Boas says, ib., p. 40, on the three persons of the demonstrative. In the paradigm to follow *x·* is what we should call a pronoun stem, comparable with the stem of Lat. *hic*, and is explained as "present visibility", *x·i* being its masculine and *x·a* its feminine. Similarly *qi* and *qa* are masc. and fem. of *q*, expressing "past invisibility".

Present Visible.

			M.	F.	Dual	Plural
Near	1st	pers.	x·ik	x·ak	x·ĭctik	x·ītik(c)[1]
"	2d	"	x·iau	x·au	x·ĭcta	x·ĭta(c)
"	3d	"	x·ix̣	x·ax̣	x·ŏcta	x·ōta(c)

Past Invisible.

"	1st	"	all wanting			
"	2d	"	qiau	—	qĕcta	qēta(c)
"	3d	"	qix·	qax̣	qŏcta	qōta(c)

In this pronominal paradigm we find every substantial element of conjugation and even see how tense also might have arisen from pronominal flexion (cf. the augment E- in IE. speech). Here note may be made of the complete conjugation of adjectives in the Athapascan tongues (v. op. cit. p. 159).

Person endings.

48. With these specific paradigms and the other general analogies before our minds it requires no great hardihood to interpret

1st sg. ES-MI EI-MI 2d E(S)SI EI-SI 3d ES-TI EI-TI

as demonstrative groups exhibiting personal inflexion, i. e. conjugation; and it is more likely a survival than an innovation when we find Skr. *asmi* = ego and *asi* = tu in the fable literature (53). After § 46 the development of copulative force needs no further illustration. The development of the sense of 'ire' from an interjectional EI (cf. Lat. EI !, identical in form with the impv. of *ire*) 'here' (come) or 'there' (go) may be illustrated by the use of Lat. *ultro !* in the sense of 'begone' (see my note on Plautus Mo. 601); cf. Ital. *avanti*. In ESMI ES- will be the nom. ES- found in Umbr. *es-to-* 'iste', Osc. *es-idum* 'idem' (see Brugmann Gr.^{2}

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[1] By adding -c the plural for human beings is made.

2, 2, 326). That -MI stands in relation to Lat. *me* and *mī*, Gr. μοὶ, and was a demonstrative of ego-deixis, seems to me past doubting. It can hardly fail to be identical with the same letters in Skr. *tás-mi-n*, which might, under circumstances, do duty for *huic* (mihi) or for *huc*. The -SI of the 2d person will belong with the article ὁ: Skr. *sá*(*s*) [cf. Vedic *să*/*sā̆ tvám* = thou (m., fem.) here]; and -TI with the article τό: Skr. *tád*.

49. I cannot think that the strong reluctance to looking on the endings -SI and -TI as pronominal arises from general objections to supposing these endings of pronominal provenance; nor is there anything intrinsically improbable in the idea I long since advanced (AJPh. 15, 414; 439) that -SO and -TO (-SI/-TI) were nearer and remoter 2d persons. The compelling objection must lie in the fact that 3d person -TI conflicts with the 2d person pronoun TU (cf. Dor. τῠ but τῡ́-νη, Lat. *tū nē*. On the other hand it agrees with 3d person *-tu* of the Sanskrit imperative,[1] and it agrees with the demonstrative τυῖ τυῖδε "huc" of Lesbian (TŪ̆ + the ῑ of οὑτοσῑ́), which contains a ῡ̆ as likely to be proethnic as the υ of ὅπυι, Skr. *ku-tás* 'unde'. Why leave for a Greek analogy the establishment of a vowel harmony between relative and antecedent? The shift from 3d to 2d person, if that is the way the cross allocation came to pass, may be compared with German *Er*, and afterwards *Sie*, for *du*; cf. also the honorific *Dero*. In Latin, in the future imperative, 2d and 3d persons are not differentiated, while Skr. *bháratāt*, 2d person, = φέρετω, 3d. In primitive Semitic the pronouns were still fluid in their reference, so that in the derived languages different allocations for number, gender, person obtain (see Brockelmann Vergleich. Gram. § 65). As for IE. TU, in view of its coincidence with the root TU 'to be strong', one may wonder if its final allocation to the 2d person was not honorific (cf. the Japanese honorifics) and TU = quasi 'your majesty'. The Japanese honorifics also "frequently discharge the duty of pronouns" (Encyc. Brit. 15. 167).

Pre-casuals.

50. Returning to the personal endings -MI -SI -TI, I am inclined to identify them with the Old Lithuanian accusatives *mi ti si*. Such forms belong to the period before cases, are adverbials like Lat. *-ce* Ir. *cē*, locative words, that is. As Brockelmann, l. s. c., puts it: Die pronomina entwickeln sich aus interjektionen, deutewörtern oder

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[1] For Indo-Iranian *tŭ* 'quidem' with 2d and 3d person verb forms see Delbrück ai. Synt. § 256, Bartholomae Wbch. 654.

lautgebärden, die ihre spezielle beziehung erst durch den Sprachgebrauch erhalten. The locative word is the phenomenon now known in IE. grammar as the suffixless locative, but one may roundly declare that it is a phenomenon of universal range throughout human speech. Let us note in Misteli, op. cit., the suffixless locatives of Mexican (116), of Magyar and Yakut (369), of Dravidian (395), of modern Persian (605). An instructive glimpse into the nature of the phenomenon may be got in Bantu, where a suffixless locative serves to indicate all the place relations (325), the *at* and *in* relation (locative), the *to* and *toward* relation (dative, locative, accusative), the *from* relation (ablative). Misteli, after giving examples (326), states, which is to explain, the phenomenon (conclusively but briefly) in the words: es sind das ort- und zeitbestimmungen, die der vollen lokativischen gestalt entbehren können, weil sie meist nur in diesem casus erscheinen, gerade wie im Neupersischen die blossen stämme von dergleichen wörtern lokativischen Sinn einschliessen. See also ib. p. 573 where, after mention of suffixless locatives in our IE. tongues, he adds: man versteht diese anfänglich sonderbare verwendung, wenn man sich erinnert, dass zeit- und ortsbestimmungen im Chinesischen zu anfang, und gewissermassen ausserhalb, des satzes und der syntax stehen.

Paradigm of ESMI.

51. But to come back to the paradigm of ESMI: when in the phrase it was preceded by vowel—or even consonant—sounds, the E- was liable to absorption or procope, as in Old Latin *cura's*, *bonu's* (from *bonus*[*es*]), *rectum'st*, or in English *it's*, etc., and it was these E-less forms that were generalized in Skr. *smas* : Lat. *sumus*, but Lith. *ẽsme* : ἐσμεν, all excep. excip. from (E)S(O)MOS. In the 2d plural ἐστὲ : Skr. *sthá* we are to see a startform (E)STHE, or E(S)-STHE, and I hold that STHE is a demonstrative element—cf. Tsimshian *st* "indicating presence or nearness" (Boas l. s. c. 379)—found also in the root STHĀ[1] (cf. Prellwitz Wbch. s. v. ἵστημι, and note the Latin interjection *est*). In the 3d person, Lat. *erunt* : ἐόντ- (ptc.),[2] *sunt* : Skr. *sánti*, but Umbr.-Osc. *sent*, warrant the startforms

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[1] In the Greek impv. ἴσθι 'es' we have IE. S(TH)ISTHI, cf. Skr. *tíṣṭha* 'sta'. The final -ι of the Greek form may come from the DHI ending of ἴθι 'i', φαθὶ 'fare', but see on Av. *bərəϑi*, § 82). On the use of STHĀ as a copula see Fay AJPh. 33, 380, § 9.

[2] The identity of 3d pl. in -ONT(I) with the pres. ptc. stem in -ONT came, I take it, by imitation of the relation between the Skr. 3d pl. pf. and the pf. ptc. See § 72.

(E)SONTI (with *o*-deflection after the accent, and before N, also in 1st plural before M) and SENTI. The form ESONTI will contain ES as explained in § 46 (cf. Lat. *ipsorum* replacing *eorumpse*) + *ĕ̄nti*, which is made up of a demonstrative *ēn* (cf. the Greek and Latin interjection ἦν/*ēn* 'ecce') + TI, as in the 3d singular. Perhaps Doric ἐντὶ, Attic εἰσὶ, never had an S- to lose, and are to be directly equated with OIr. *it* 'sunt'.[1] Cf. also § 70, and note Homeric ἐν 'est, sunt' (see Fay, AJPh. 16, 20).

Paradigm of ESK̂O.

52. As for the IE. paradigm of Lat. *escis escit*, Homeric ἔσκον ἔσκε, I take it that the combination ESK̂E was like EIMI, or rather that ESK̂Ō ESK̂ESI ESK̂ETI varied with ESMI etc., the variation ES/ESK̂E being like that of *huius*/*huiusce* in Latin. On the use of *escit* in forming inchoatives see § 27. In Skr. *pṛcchā́ti* : Lat. *poscit* we may start with a weak noun *pṛk̑s⁀* 'asking' (: Lat. *prec-es*, action noun) + [ES]K̂ETI. The same sort of haplology would obtain also in διδακς⁀[εσ]κω.

Copulative verb-forms = demonstratives in Sanskrit.

53. Before leaving this topic it is interesting to note that Sanskrit *asmi* and *aham asmi* act the rôle of *aham*, *asi* and *tvam asi* the rôle of *tvam* (see PW.^{1} I, p. 536 s. v. *as*, 6; also Speyer Skr. Syntax § 311, 3). I should also interpret *asti* at the beginning of a fable (op. cit. 311, 2) as 'here now'. In the fable literature also—that is, in a genre that might retain archaisms—is the home, perhaps, of *asmi* = *aham*, cf. Kath. 25, 187 (cited by PW.^{1} l. c. fn.) *nṛmā̃ṅsam asmi vikrīṇe* = homini-carnem sum (i. e. ego) vendo. Here the reality is that *vikrīṇe* (on the etymology see § 86) = *vendendo* is the infinitive out of which the middle grew (57). In an example like *tvā̃ṁ asmi vacmi* (PW.^{1} l. c.) = te (i. e. tibi) sum (for ego) dico the repetition of *-mi* is suggestive of the concords in Bantu, e. g. *ñgu-mu-ti ñguno ñgu-gwa* = *this‿tree* this‿here this‿falls (see Encyc. Brit. 3, p. 361).

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[1] Thurneysen air. Gram. § 176 gives for the examples of disappearance of *s-* in proclitic words only the further examples of (1) the article *ind a*, etc., after prepositions, *-sind -sa*. Here, though I have no competence in Celtic phonetics, I should like to ask if the *s-* may not belong to the preposition, cf. Lat. *ab/abs*, ἐν/εις, etc. (2) *amail* 'sicut', adverb-conjunction from *samail* 'similitudo'. But Skr. *amū́thā* 'auf jener weise, so' suggests that *amail* may owe its loss of *s-* to some no longer discernible cognate of *amū́thā* playing upon *samail*. If this suspicion is correct, then *ind* is to be derived from ENTOS (not SENTOS) : Delphian ἔντε 'dum' (ἐνταῦθα 'then'?).

The verb-paradigm analytic.

54. But let us leave the discussion of the demonstrative origin of ESMI and EIMI and see how we can account for the standard IE. verb paradigms of the thematic type—also for the root flexion, in part—on the theory that these paradigms are analytic in their origin. The variety of morphological problems that meet a solution by the assumption may justify my analysis even in the eyes of those who will have it that because we meet, let us say, with the type of Skr. *hánti* 'kills', *bhárati* 'bears' as early as with *éti* 'goes' *ásti* 'is' therefore for us they must be as early.

The thematic diphthong : EIMI.

55. The argumentation of recent years to show that *φέρεις* represents an original IE. form (see Brugmann IF. 17, 178; Meillet Mém. Soc. Ling. 14, 412) has failed to advance its strongest pleas. These lie in the diphthong of the Skr. middles *bháre-the bhā́re-te* (2d and 3d dual, and as duals archaic), subj. *bharāit*(*h*)*e*, wherein the only thing "middle" is the final *e*, which spread from the 1st and 3d singular over the paradigm (57). The strongest argument of all, however, lies in the fact that in the optative of the type *φέροις* we have the post-accentual deflection of the EI of *φέρεις*.[1] The allocation of modal force to the OI diphthong (cf. 35) was doubtless a growth. Original modal indifference may have reigned as it survived, or developed, in Skr. *so 'ham vajaṁ sanāmi*/*saneyam* = hic ego bonum adipiscor/adipiscar (see Bloomfield l. c. 14). Given the original moodlessness of the optative, and we may ask ourselves whether Lat. *velis*, as the equivalent of *vis* (cf. e. g. Lindsay, Lat. Lang. 515: in Plautus velis and vis are used as the metre requires, without difference of meaning[2]), is not from WELEIS, like *φέρεις*, and entirely identical with Gothic indic. *wileis* 'wilt', now derived from the optative, i. e. WELĪS. There was little reason why the verb "will" should have developed an optative—save by way of attraction to a foregoing dependent optative (see my Mostellaria Introd. § 67, 4)—but much reason why it should have an emotional

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[1] I am not unaware of the BHERĒI, etc., bases, to which I have in my time yielded allegiance, cf. e. g. TAPA. 37, 11. These bases are, in a manner of speaking, infinitives, and in that sense I still yield allegiance to them.

[2] Herein lies the secret of the Latin subjunctive of the ideal 2d person: it is a premodal form. As for Lat. *vis*, it may be from *velis*, enclitically attached to a word like *si* and reduced in the sentence squeeze to **silis*, with subsequent restoration of *v* from *siuolt*.

diphthong (35). In Gothic *wileis ei* may represent either EI or I. Only early inscriptions, and unfortunately no such have yet been found, could tell us whether Lat. *velis* contains original ī or EI. In the Gothic 2d and 3d singular *habais habaiþ ai* may represent OI, and Möller (ap. Streitberg Urgerm. Gram. p. 307, anm.) constructed these endings "rein willkürlich" from OISI OITI. But they may be "optatives" (pre-optatives) with indicative function, and the verbs of the class are, in fact, "in ihrem grundstock primäre verba" (so Streitberg l. s. c.). Curiously enough, the optative corresponding to *habais* is *habáis* (*-áis* from -ĒIS), with endings identical with the Greek subjunctive φέρῃς, from *bherēi*⁀[*ei*]*si* (? or [E]SI, cf. § 69). Cf. *āi* in Skr. *bravāite* (dual) 'dicatis'. In Latin *habēs*, also not a causative, Ē is likewise due to the startform *habē*(*i*)*s*.

56. How are we to account for these forms with thematic diphthongs? On Attic vases we have the imperative πίει = πίε, and Doric ἄγει = ἄγε; and these, especially πίει, look like the type of infin.-impv. found in Skr. *pra-mīye* (40). Corresponding Avestan infinitives have *-āi*, e. g. *jayāi* 'vincere', *vindāi* 'reperire', *fra-vākāi* (*-vāk-*: Lat. *vōc-* ?); and the two first present the "root" as found in the present stem, while *fravākāi*, apart from the length of *-vāk-*, suggests Lat. *pro-vocāre* (? with *ā* from ĀI). In Balto-Slavic the 2d sg. of the present comes from -EI (without -SI/-S), and the Latin imperative *nolī* seems also to belong with the infin.-impv. in A^{x}I or ĒI (with a possible grade *-ī*, cf. § 59). I explain the relation of φέρεις to the Balto-Slavic form on the supposition that an infinitive φερει⁀ was followed by EIS(I) 'is', whence, with haplological shortening, *φερεισ(ι). Suffixless locatives (? cf. on θεν-έει, § 68; 38) will also have played a part. Lat. *moneo mones monet* come from MON⁀EYO ⁀EYESI ⁀EYETI, a later flexion type than EIMI EISI EITI. Verbs in this conjugation might also come from the long vowel infinitive, say *habēi*⁀[*ei*]*si* (55).

Infinitivals with ellipsed copula.

57. As these complexes long remained separable various conditions obtained, so that we may legitimately suppose that a type φερ⁀EISI, with participial prius, existed alongside of BHEREI⁀-[EI]SI, with infinitive prius. It may also be that the infinitive BHERĒI picked up its person endings by imitation of EISI and ESI (cf. on the Bantu concords § 53). The Balto-Slavic type of 2d person is to be explained by ellipsis of the copula, whether EISI or

ESI.[1] By the same ellipsis we account for the Sanskrit "middles" *duhé* (sc. *asmi*) = mulgendo <sum>, *bhárase* (sc. *asi*; cf. Parmentier in Mém. Soc. Ling. 6, 391), *duhé* (sc. *asti*) = mulgendo <est>. We have also the 1st sg. *kṛṣe* 'facio' in RV., with *-se* as in ὀψεῖ (65). The infinitive finally allocated to the 1st person ended in -AI, but to the 3d in -EI. Of this the proof is furnished by the equation of Lat. *vidi* with οἶδα, startform WOIDAI with loss, under some samdhi condition (cf. § 1, 1), of final -I. From 3d person οἶδε I infer an infinitive in -EI. In the Skr. 2d plural *vida* we also have a weak-grade infinitive with samdhi loss of final -I. Thus distinction of person was effected by allocating the diphthong in -AI to the 1st, in -EI to the 3d sg.; but the samdhi form in -A^x (sometimes from an infinitive in a different vowel grade) to the 2d plural. There was absolutely no uncertainty, as time went on, about these forms, granted the actuality of merely a contextual subject, any more than there is uncertainty to-day with English *I you he loved.* The Skr. infin.-impvs. in *-e* (*-se*) *-adhyai* are of all persons (see Speyer VSS. 216, d).

58. In Greek, as well as in Balto-Slavic, we have the infinitives without a copulative verb, whether EIMI or ESMI, viz.: in the Attic 2d sg. middle φέρει (cf. on Skr. *bhárase* §57), in other dialects, with long diphthong, φέρῃ. The -EI infinitives may also function as 3d sg. of impersonal verbs like μέλει, sc. ἐστὶ; cf. Lat. *curae* <est>. True, μέλει may at some time have picked up a -TI to match other verbs, as Lat. *decet* (from DECĒI) probably did.

Thematic Ĭ *from* EITI; "*causative*" -EYE-.

59. Of anything that may be rightly called proof of the existence of EISI in the BHEREISI type nothing has been yet offered. A special group of Sanskrit verbs, special and therefore probably archaic, seems to me to furnish the proof. Omitting sporadic forms of the roots *çnath* 'forare', *jan* 'gignere', *vas* 'vestire' and possibly one or two more, there is a particular semantic group containing the forms *bravīmi* 'dico', *bravīṣi* 'dicis', *çvasiti* 'fremit' and forms from other breath-and-sound roots: *rud* 'flere', *an* 'spirare', *stan* 'tonare', *vam* 'vomere', *svap* 'dormire'. The *i* in these Sanskrit forms has, of course, been interpreted as *ə*, like *q* and *g*, a symbol much beloved when linguistics was becoming, to its

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[1] Cf. RV. 1, 32, 9 (see Speyer VSS. 172), where the inconcinnity of *çaye* after *āsīd* 'erat' perhaps means that *āsīd* is to be supplied again with *çaye*, and its infinitival accent restored.

great improvement, minutely phonetic. When we put Skr. *çvasimas* beside Lat. *querimur* their secret comes out. Their startform was KWES-[ES]⁀ (participial, ? nom. plural) + IMOS, and the type does not differ from the iterative Plautine combinations *balitantes eunt*, *flens abiit* (cf. *exibant flentes*, Naevius)—see my lists, probably the largest accessible, in AJPh. 20, 154–157. It was because this combination with EIMI had a frequentative value that it was kept alive in this group of breath-and-sound words. In imperfects like *açvasīt*, *ī* is either like the *ī* of *īmahi* 'imus' or has arisen after the accent of an injunctive *çvásīt* from K̂WÉS⁀ĒIT (ĒIT impf. of EIMI), see Kretschmer KZ. 31, 325 sq. Skr. *vam⁀imas* : Lat. *vom-imus* shows a participial or infinitival prius WEM⁀ or WOM⁀ (? from the root WĒ 'flare'; cf. § 38) + IMOS, whereas ἐμέω reveals in the posterius the flexion EYO EYESI EYETI (with secondary thematic diphthong in Greek). Here note the correspondence in regard of *ī* between Epic Skr. *svăpīta-* and Lat. *sōpītus*, the one from **svapi⁀ ī̆tos*, the other from SWŌPI⁀ Ī̆TOS (for SWŌPI cf. *anu-ṣvā̆pam*, RV.) 'somnum (ad)itus', euphemistic for 'interfectus'. Latin usage (only *sopitus* in Cicero, *sopitum fuisse* in a bit of old narrative in Livy) justifies starting with the participle with the euphemistic sense of 'interfectus'. Thence *sopīre*, a back formation, 'interficere' [Correct Ennius Sc. 274 from *sopivit* to *sopiti*?]. Skr. *svāpáyati* (also = interficere) is from *svāpay⁀[ay]ati*, and will have reached its causative meaning in some such way as *sopire*. There can be no reason to believe that -EYETI was originally causative; that the *-eo* of Lat. *doceo* is more causal than the σκω of διδάσκω—nor even that 'teach' is a causative of 'learn'. We have in OBulg. *nositi* 'ferre' (with an original long penultimate *ī*) a like formation (pace Meillet Mém. 13, 374). It is curious how the type continued to ring true in late Latin *rudiunt*, which might be from RUD⁀(I)YONTI, unless it were more likely due to pf. *rudivi* (cf. § 66). In Lat. *queo* composition with *eo*, though in a mistaken sense, has long been admitted. The root was K̂EK^{w}, in Skr. *çaknóti*, and this root meant as a participial 'potis'. In Latin K̂EK^{w} gave *cequ*, and with the negative, *necequ* (cf. for *na* + *çak* in Sanskrit Delbrueck ai. S. 429), whence by haplology *nequ⁀eo*. Skr. *yāt-áyati* when combined with *ā-* = hinstrebt zu, i. e. ζητῶν εἶσι (petens it). The prius *yāt-* is alive in Skr. *ṛṇayā̆t* = debitum petens, cf. *yátate* 'petit' and ζητηταί = quaesitores. In Greek, ζητέω is identical with Skr. *yāt-áyā-mi*, but has a more restricted range of meaning. In the future ζητήσ-ω, aor. ἐζήτησ-α (18), the prius is *ζητής 'quaesitor', preserved in the name of Ζητής, the ravishing Boread. For EIMI complexes in the perfect see § 66.

60. In *brávīmi* 'dico' (ultimate root in Lat. *memorat*) the long vowel was generalized. It may have been brought over from (*a*)*bravīt* (cf. §§ 24, 59) but is more like to contain an infinitive prius *bravī̆* (locative to a U-stem as *át-tav-e* 'edere' is dative to a TU-stem). Cf. *hávītave* from *havī̆* + *ī̆tu-*, a combination substantially repeated in Lat. *amatum iri*. In the somewhat formulaic Vedic sentence *ihá bravītu yás u tád cíketat* the Latin rendering 'hic dicere‿eat qui quidem hoc sciat' ("wer dies weiss, der sage es hier", Grassmann Wbch.) fairly represents in *dicere‿eat* my interpretation of the complex welded into *bravītu*; cf. ἀλλά τις εἴη εἰπεῖν in § 2, 4. This sentence type is also found in the Avesta, e. g. in V. 3, 27, *baδa iδa aēni bəreθi* = enimvero hic eam (hortatory = ibo) ferendo (i. e. feram). Here I note my explanation of *infitias*(*e*) *ire* (Cl. Rev. 10, 184), but *infitia*(*n*)*s* is not to be excluded (AJPh. 20, 157). In these combinations with 'ire' there is a strong frequentative note, as also in the breath-and-sound group (59): add from Livy to the other examples *canentes ibant*, *minantes ibant*, *ovans adit*, *ovans* and *triumphans init*, *contionabundus circumibat*. These complexes have that vivid note of reiteration that implies a spectator (cf. also Speyer VSS. § 205 b).

Latin amaret and other EITI *forms.*

61. It is interesting to observe that the combination with EIMI either survived (cf. Av. *aēni bərəθi* § 60) as a never forgotten potentiality of combination or, as Brugmann has recently suggested (IF. 30, 350), was revived in Latin *amaret*, which is from *amare* + EYETI (or the impf. ĒIT ?). I feel great confidence in Brugmann's combination because it so well suits sundry imperfect usages, e. g.:

Mo. 462: qui modo pultare potui si non tangerem
'why, how could I have knocked if I wasn't going to
touch the door?'

But the problem of *amaret* is wider than Latin. The agreement between ἱσταί⁀ητον ἱσται⁀ήτην (infin. prius ἱσταί⁀, cf. on ἴσθι § 51 fn.) and Skr. middle aorists (dual) like *bhare⁀yāt*(*h*)*ām* (infin. prius *bhare⁀*) is too close to admit of their separation. The archaic dual ending *-yātām* either stands for YĒ-TĒM (: YĒ, cf. § 34) = 'they two went' or, taking *y* as a passing tone from the previous diphthong *-e*, is for Ē[I]TĒM : EI. The entire optative paradigm ἱσταίην

-ης etc. shows the same composition. In the indicative we have Homeric *(ἐ)-μίγ-ης* from the infinitive *μιγ[ἔι]*⌒+ Ē[I]S. Here the prius was taken passively = *misceri*, not *miscere*, + *ibas*. The optative was from *μιγ[ει]*⌒+ *εἴης*.

The OI *grade in the optative.*

62. A difficulty that may be raised as to the correlation of the -EISI and -OISI forms meets an easy solution: -EISI belonged under the accent, deflected -OISI after it, WIK̂EÍSI 'intras' but BHÉROISI 'fers'. The original divergence in accent lay, as in Sanskrit it has been preserved, in the infinitive prius. Traces of -ĒIS may also obtain in the Sanskrit forms like *kramīs* (v. Macdonnell l. c. § 529), and a few forms in *-āis -āit* remain (see Lanman's note in Whitney's AV. 6, 32, 2). These forms have no certain connection with Lat. *erās*, which owes its form, as has been otherwise suggested, to the analogy *amabo* : *amabam* : : *ero* : *eram*. I date the analogy at the time when *-fam* still meant 'eram'. The weakening of the *-ēis* forms to *-īs* (59) belonged to a different period of vowel gradation from the deflexion of -EISI to -OISI, unless indeed the difference is one of position in the ultima and the penultima.

Syntactical interpretation of the EITI *complexes.*

63. The syntactical interpretation of the complex BHEREI⌒[EI]-SI remains yet to give, viz.: that we owe to this combination the future-present and the various conative shadings. Speyer notes (VSS. § 215) that the Sanskrit infinitive, still nominal, is prevailingly future. In Latin *amatum iri* the future note has been regularized, as much so as in Skr. *dātā'smi* (5) in contrast with *auctor sum*.

The Latin ē-future an EITI *complex.*

64. The possibility that this future type is an Ē-subjunctive cannot be gainsaid. Phonetically, however, under the conditions pointed out for *tegēbat* (43) and *acciēbo* (40), *tegēmus tegētis*, *capiēmus capiētis*, *audiēmus audiētis* have an *ē* that may represent either the -EI of *φέρεις* or the OI of *φέροιμεν φέροιτε*; or they may contain the infinitive prius with long diphthong (§ 58).

Greek desiderative complexes in -ειω.

65. Greek preserves a small, but interesting, group of forms of desiderative force where composition with EIMI seems indubi-

table. Monro's list for Homer, with his renderings, contains the following words:

a) *ὀψεί⁀οντες* "going to see". Here the prius *ὀψει-* is an infinitive in -SEI, cf. Skr. *upa-prák-ṣe* (root *pṛc*) 'to unite', *ji-ṣé* 'vincere', *stu-ṣé* 'laudare', Lat. *da-rei*,[1] etc.; note -SĬ in Lat. *esse*, *velle*, etc.; cf. § 39. The posterius was (I)YONTES: Skr. *yántas*.

b) *κακ-κείοντες* "going to bed". Prius *κατ(α)- κεy-ει⁀* + (I)YONTES. Cf. Skr. *svapīta-* (59) 'gone to sleep'.

c) *πῑ-όμενα* "going to drink". The startform was PI[YEI]⁀YOMENA = bibere‿iens.

d) *δραίνεις* "thou art for doing". I see in *δραιν-* the blend of an infinitive DRĀM (like Skr. *sthām*,[2] RV. 9, 85, 11, cf. Wolff l. c. 89) and DRĀI (as in Skr. *prati-mǟi* 'imitari': *pra-mé* 'formare'). But the division *δραί-νεις* is also posssible, cf. § 85.

e) *κταν-έοντα* (Σ 309) "him that would slay" (Lang Leaf, Myers). For *κταν-* see § 17; *-έοντα* = Lat. euntem.

Latin seek-and-search group; *pf. in-ivi.*

66. Latin also has an abnormal group of verbs meaning 'to desire, seek', with perfects in *-ivi*. Hitherto, in agreement with most scholars, I fancy, I have thought *cupīvi* the original on which the others were modelled. But in view of its cognates (see Walde s. v.) *cupire* is as abnormal flexionally as **capīre* would be. The verbs to start with are *quaesivi* or *petivi*, with posterius *⁀ivi* 'I have gone'. In *quaes⁀* and *pet⁀* I suspect that we have participials rather than infinitives. The derivation of *quaes⁀* from a nominative in -s^s (§ 1) explains the problem of retained -S- in Latin (note also *quaeso* from *quaes⁀[es]o*, as in § 67). I recognize in *qu-aes⁀* a compound of the preposition SKU: *ξύ(ν)* : root SEK^w (see Fay AJPh. 33, 397^1) + AIS (*əis*) 'pursuer' (cf. Fay IF. 26, 27 sq. on *αἵμων* 'hunter'). The prefix SKW = co- implies a body of searchers rather than an individual, and the plural quaes[es]⁀ivimus may have been the prior form (cf. *petes⁀sunt* § 67).[3]

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[1] It should be of common knowledge that the infinitive is of either voice, and why (cf. e. g. Fay AJPh. 15, 221; for the fact cf. Speyer. l. c. § 216 b, and [unconsciously] Goodwin op. cit. § 771).

[2] In AJPh. 16, 16 I explained *duhā́m* as 'to the milking', i. e. "mulgeat", from a cry, quasi "ad mulgendum!" Also note Bloomfield's translation (AV. 5, 30, 13) of *çárīram asya ṣáṁvidām* by "His body shall collect itself (corpus eius <se> colligat).

[3] My derivation of *accerso* in TAPA. 37, pp. 5, 24, seems to me still entirely convincing, and the assumption of anticipation of *r* in *arcesso* still not improbable. But *arcesso* may be of different origin from *accerso*, for instance from

The thematic vowel: ESTI *conjugation*; *root-conjugation.*

67. The injunctive future aorist desiderative complexes studied under *rex⁀ero* (8 sq.) were relatively late Indo-European. The combinations represented in the φέρεις type were probably old and moribund at the time of the upbreak. What we know as the O/E conjugation was early also, but formed, as I hope to show, out of complexes with infinitives and participials (agent nouns) with ESMI, analogically modified by the EIMI complexes. Later complexes with ESMI, that is complexes that show the -S nominative prius, are also found, as in Skr. *rákṣ⁀ati* 'protects': ἀ-λέξει. These have gunated forms as compared with the vriddhied type of δείξω, the zero-grade of Skr. *dikṣát* (14). Note also Skr. *dveṣ*⁀[ES]*mi* *dveṣ*⁀[ES]*i* *dveṣ*⁀[ES]*ti*, plural *dviṣmás* etc., graded like *i-más* 'imus'. The mode of flexion here is absolutely identical with a complex like Herodotean ἐπίτεξ ἐοῦσα, whence we might have had *ἐπιτεξ⁀[εσ]τι 'parturit'. Cf. Skr. *dāṣṭi* 'honors' (or *tāṣṭi* 'builds') from a vriddhied prius DĒK̂S⁀[ES]TI; or Lith. *sė́st* 'sedet' from SĒ(D)S⁀[ES]TI. The pervasion of the plural by the singular in these complexes will have been due to the formations with infinitive prius (cf. §§ 4, 38). In words like Lat. *fers* I see nouns with (a secondary or retained) nominative -S (see § 17); i. e. *fers* is from BHERS⁀[ES]I, Skr. *bhármi* from BHERS⁀[ES]MI, with loss of S between consonants. Formations of this date should have had in the plural BHER-ES and in a few Latin words that plural not only survived but went into the singular. The type is found in *expetes⁀sunt* (or *expetes*^{s}*⁀unt*?, 74) whence *expetes⁀so* (cf. § 66 fn.).

68. The IE. paradigm of the complexes with G^W^HEN or G^W^HENEI (§ 38) would have been, with haplologic shortening,

Sg.	GWHEN⁀EIMI	GWHEN⁀EISI	GWHEN⁀EITE
Pl.	" ⁀EIMOS (ǏMOS)	" EITHE (ITHE)	" EYONTI (I)YONTI

The actual survivors of these complexes have been noted above (59, 65).

69. In the ESMI complexes also we may even count on the infinitive prius; cf. *āstam . . ran* § 38; and Av. *Yimo asti bərəθe* (V. 2, 7) Y. est ferendo ("ist in besitz"), i. e. fert, adipiscitur. But a participial might also be admitted, with the feminine BHERĀ,

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**ad·seques⁀sunt.* The prius would have meant 'pursuers, apprehenders' (cf. mustela mures adsequitur). Now supposing *d* analogically reinforced in the compound a secondary regressive assimilation to **adzeques* may have resulted, and thence *arcessunt*, a synonym of *accersunt*. Note in the Avesta the zero-grade form *a-sk-arə* 'sie vergingen' (Bartholomae Grund. Iran. Phil. 1, 310, 15).

neuter BHER, as well as the masculine. From BHERĀ, 2d sg. BHERA'SI (see § 51), came the *ā*-forms called subjunctives, but cf. Lat. *-bam -bas -bat, eram eras erat,* which were probably never subjunctives at all (81 fn.). As in *expetes-sunt* (66) the masculine plural BHERES⁀ may have existed and have gone into the singular (where neuter BHER was perhaps already to be found)—with loss of its -ES in the 2d plural—by an analogy yet to be shown (70).

The Paradigm with ESTI.

70. Pl. BHERES⁀[ES]MOS BHERES⁀[ES]THE BHERES⁀[ES]ONTI.[1]

Of these forms there is at least one that remains, whether the posterius was ESTHE or STHE, quite intact, viz.: in Greek φέρεσθε, 2d pl. middle. In the singular the paradigm, with a suffixless infinitive or neuter participial prius, was

Sg. BHER⁀ESMI BHER⁀ES(S)I BHER⁀ESTI.

With the 2d sg. Skr. *bhárasi*[2] is identical. Thus there existed in the proethnic speech rival singulars BHER⁀EISI and BHER⁀ESI, BHER⁀EITI and BHER⁀ESTI, resulting in an analogical 3d sg. BHER⁀E[S]TI. In the plural BHER⁀EITHE stood beside BHER⁀ESTHE, resulting on the one hand in Skr. *bhára[s]tha,*[3] on the other in Lith. *eĩ<s>te* 'itis'. In Greek, BHERESTHE survived as a middle because of σθ in infinitives and forms of τίθημι (82). In 1st plural BHERESMOS, S was dropped after the pattern of BHER⁀(E)ĬMOS (68), and BHEREMOS then deflected to BHEROMOS. On the model of EI⁀MOS to EY⁀ONTI (Lat. *eunt*) the pair BHEROMOS and BHERONTI came into being—unless ENTI (deflected to -ONTI) be recognized in a word with suffixless infinitive prius like Skr. *bhan⁀anti* : Lat. *dan⁀unt* (: Av. *dąn* § 38); cf. § 38 fn., 51.

71. The 1st person BHERŌMI is still unaccounted for. This will have come from BHERESMI as BHEROMOS from BHERESMOS. The secondary ending without *-i* will have appeared in the form E)BHEROM : BHERŌ : : Skr. *ahám* : ἐγώ(ν). Observe this ending *-om* also in the pronouns *ayám* (as a copula in RV.; see § 46), *idám* etc. For the phonetics of ἐγώ(ν) cf. δῶ: Skr. *dam-*, stem or suffixless

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[1] Or BHERES⁀ONTI ; see § 51. The penultimate O is due to deflection.

[2] In Armenian all 2d persons, if projected back to the mother-speech, end in ESSI, and are explained by Meillet (Gram. § 87) as due to the analogy of ESSI = Hom. ἐσσὶ. This is scarcely more probable than to suppose that BHER⁀ESSI, not BHER⁀ESI, survived in Armenian.

[3] The aspiration may well have belonged at first to the 2d plural (E)STHE, wherein we have the element ST(H) (see § 51), and not to 2d pl. *EITE 'itis'.

locative or genitive with lost (E)S, in the compound *dám-patis* 'im Hause Herr'; cf. Av. *dąm*, ἔν-δον.

The perfect endings; elliptic perfect forms.

72. If the three stems of the Sanskrit perfect participle [cf. 40 fn.] from EI 'ire' had representatives in Latin they would be *ī̆vōms-*, *ī̆vos-*, *ī̆yus-*, with probable doublets, due to levelling, *ī̆yos-*, *ī̆vus-*. The Latin correspondent of Skr. 1st. sg. middle **īye* would have been (as it is) *ī̆ei* and thence—with intrusive *v* from the participle doublets—*ivi*.[1] From Skr. 3d pl. active *īyús* we should expect in Latin **ius*, but we actually have *ierunt*. This *-runt* I take as the equivalent of Skr. *-ran* of the 3d pl. optative, but sporadically found in other forms also; see the lists in Dottin's Les Désinences Verbales en R, p. 19. The equation of Skr. *dadīran* (3d pl. opt. middle) with Lat. *dedī̆runt*, OLat. *dedrot*, would be perfect were it not for the length of *ī*, but we have *ĭ* in *á-cakriran* plupf.: *cakriré* pf., and in *á-jagmiran*: *jagmiré*. Note also that Skr. *da-dhús* is matched by Av. *dā-dar*^{ə}. Now I take *īyús* to end in original *-s* not *-r* and to be a haplological form of the participle in the nom. plural *īyuṣas*[2] (cf. *emuṣám*, *cakrúṣam*, acc. sgg. with weakest stem), with omitted copula, say, ESONTI or ĒSON, i. e. *īyuṣ[as]⁀(ēson)*. For the type of perfect cf. ἐμοῦ οἱ νόμοι ἀπεγνωκότες εἰσί (Lysias) "the laws have acquitted me" (Goodwin l. c. § 45).[3] The corresponding form in Avestan, accidentally not attested, would have been **īyar*^{ə} = Umbr. *ier* (92). These forms belong with Skr. *iyárṣi īyarti* 'is it', which are blended out of the roots *ī* and *ar*. The ending *-ar* was productive in Avestan and in the Gāthas appears as *-ar*^{ə}*š*, *-š* being the nominatival *-s* of the tautological noun **ī̆yar⁀š*, cf. the gen. sg. of agent nouns in *tar*^{ə}*š* from -TOR(E)S. (On Skr. *-tur* see § 89.) A similar shortening would have produced a nom. pl. **ī̆yar*^{ə}*s* from **ī̆yar(e)s*. The same root *ar*, with a byform *īr*, is also to be recognized in the Skr. endings *-ire -iran* already mentioned. The forms in RONT(I), like Lat. *dedĕrunt*, have an infinitive prius in -E(I) + RONTI : ER : : Skr. *yanti* to EI. These complexes with RONT(I) and other forms of ER were never fully developed, but range most widely with the Skr. roots

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[1] Was this one of the chief sources of the *-vi* perfects in Latin?

[2] Inversely after the relation of 3d plur. *īyús* (pf.) : **īyuṣas* (ptc.) a participle EYONTES (Lat. *euntes*) was created to EYONTI (Lat. *eunt*).

[3] Entirely analogous, it would appear, to the Amharic constructive mood; cf. *hēdo* (he‿having‿gone) *-al* (he‿is) with Lat. profectus est. See Alone's Short Manual p. 21.

çī 'to lie' and *duh* 'to milk' (see Dottin, l. c. p. 22), and precisely because of the availability of the phrases 'to go to bed' and 'to go to milk'.[1] Outside of Sanskrit, cognates of the auxiliary verb ER 'ire' are found in Eng. *art* 'es' and perhaps in Lith. 3d sg. (dual, pl.) *yra* 'est'.

73. Returning to Lat. *ded⁀ĕrunt*, its prius was the infinitive DEDAI (cf. Skr. *çrad-dhé* § 38), which, under the conditions assumed for *tegebam* (43), would have yielded *dedē⁀runt* in the complex. In *dedĕrunt* the prius is DED[A^{x}I] + (E)RONTI. In *dedĕre* I equate *-rĕ* with the *-re* in Sanskrit *çakriré*, taking *-ĕ* as the samdhi variant of -EI (§ 1, 1).

74. The assumption that Skr. 3d pl. pf. *īyus* is a pf. participle, with omission of the copula, meets its full justification from the Italic dialects. There the 2d sg. *benus* 'venisti' is from *benus's*, like Lat. *rēctu's* etc. in Plautus; and 3d sg. *benust* is from *benus⁀(e)st*. In the 3d plurals Osc. *angetuzet*, Umbr. *haburent* (if these are not analogy forms, cf. Buck Elem. Buch § 193), either the participle in *-us* + 3d. pl. *set sent* 'sunt' lost one *s* before rhotacism set in, or we have to recognize a form ENT(I) 'sunt', as suggested for OIr. *it*: Doric ἐντὶ (51). On the future perfects Umbr. *benuso covortuso* see § 92.

75. In Lat. *ded⁀imus*: Skr. *dad⁀imá* we have a posterius in IMOS (cf. on *vomimus* § 59). The prius *ded⁀* will have been submitted to some analogy, probably of the 2d plural below. The Skr. duals *-athus -atus* are the *-athas -atha* of the ordinary thematic flexion, influenced by the *-us* of *īyús* etc. Likewise in Av. 3d dual *-atar* we have the trace of **īyarᵊ*. In Latin *dedi⁀stis* the dual *sthes* (: *stha* § 51) is still alive and the prius is an infinitive. The 2d singular of the "contracted" type in Latin, as in *adduxti*, ended originally in STHAI, a diphthongal infinitive (sc. es) preceded by the agent noun *dŭx* or **doux*. In *nosti* (see also on ἄ-γνωστος § 80) we may have an infinitive prius ĜNŌI, like the Avestan forms in § 4; or an agent noun ĜNŌS (16). This STHAI, besides being preserved in δόσθαι etc. (82), is open to clear vision in the Avestan sentence *tūm no Aϑraom zaotā⁀stē* (imperative-infinitive) = noster, O A., tu flamen‿stare. This use of *stē* (from STHĀ not ES, see Fay AJPh.

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[1] Notwithstanding the tendency of recent years to replace the "milkmaid" by the "suckling", it may be remarked that if the agent suffix TER means 'faciens' (see §§ 88–89) then Skr. *duhi-tár-* 'daughter' originally meant 'in‿mulgendo faciens' (unless here -TĒR- = 'iens': Skr. *tárati*), whereas θυγά-τηρ, with secondary accent for *θυγα-τήρ, had originally an accusative prius DHUGHOM reduced, with loss of aspiration before the nasal, to DHUGM̥. Cf. λάβον in 82.

33, 381, 9) is only a special case of a combination found in RV. 6, 63, 4:

a) ūrdhvó vām agnír adhvaréṣu *asthāt*
c) prá *hótā* gūrtámanā urāṇáḥ
sursus noster Agni in sacrificiis *stetit* (gnomic)[1]
porro *flamen* gaudi‿mens delectus

Certainly *zaotā stē* is not to be separated from *zaotarəm stayata* in Yt. 10, 89 = flaminem constituit. As everybody's mind has been committed in favor of -THA instead of -STHA in *οἶσθα* : Skr. *véttha* 'nosti', ready acceptance for -STHA—an explanation that I advanced in AJPh. 16, 16—is not to be expected. Certainly -THA had been proethnically generalized from consonantal combinations wherefrom the S had been extruded as, say, in Goth. *skalt* 'shalt'. This generalization aided in the introduction into Skr. 2d singulars like *ni-náy-itha* of ‿*itha*, 2d pl., = '*itis*'; here *ni-nay-* is an infinitive to the root NĒI (Skr. *nī*, see § 85). Still the range of *-σθα* in Greek (v. exx. ap. Brugmann Gr. Gram.[3] § 411, 3) makes for -STHA, and we have further flexion forms of STHĀ in Homeric *ἐγρηγόρ‿θᾱσι* (posterius = STHĂNTI : Lat. *stant*), impv. *ἐγρήγορ‿θε*. To the 2d sg. in -S)THA we owe the aspiration in *κέκλοφ-α* and its kind (2d sg. **κε-κλοφ-[σ]θα*).

Conjugation complexes with STHĀ.

76. Lithuanian has a somewhat large body of presents in *-sta-*, as to which see Wiedemann Gram. § 181. These I derive from the root STHĀ inflected as STHO/E, cf. Skr. *tí-ṣṭhati*, Lat. *sisto*. Their general sense is inchoative, but the frequentative might have developed as well; cf. the participial combinations cited above (3–4)[2] and Speyer VSS. § 205, b. The Avestan form *zaotā‿stē* (75) is

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[1] The "gnomic" tenses are survivals from the tenseless period. They lived on in proverbs (cf. Gildersleeve l. c. § 255, for the range of usage) because sentences of proverbial content brought their tenselessness down with them from the primitive time. Cf. on Skr. *asmi* = ego in fables (53). Note the gnomic use of *erit*, the form combined with *rex* etc. (8 sq.), retaining its tenselessness in Plautus Mo. 1041:

qui homo timidus *erit* in rebus dubiis nauci non *erit*,

followed by a line revealing the antiquity of what really is a sort of proverb:

atque equidem quid id esse dicam verbum *nauci* nescio.

[2] Note the combination of 'stare' with a participle in *στῆ δὲ μάλ' ἐγγὺς ἰών* (Iliad, 4°); cf. with a participial *φονέα με φησὶ . . καθεστάναι*; *ἄπαρνος δ' οὐδενὸς καθέστατο* (Sophocles). In Latin we have *restant* fodantes (Ennius); *stabant* orantes, *perstabat* memorans (Aeneid); *stat* expectans (Cicero Cat. 4, 2); potentes *stamus*, i. e. sumus (Propertius 4, 22, 21).

typical of how the combinations might have looked at first. Homeric *ψευ[δσ]⁀στήσεις* (T 107) = "thou shalt play the cheat" is every whit as plain as Lat. *auctor es/eris*. In the Homeric frequentatives *νευ(σ)⁀στάζων, ἑλκυ(σ)⁀στάζων*[1] the posterius contains the *d* of *στάδ-α* 'stagnantem'—a D that has come in from the *sedeo* sept—inflected after the YO/E class. In Latin, *gu(s)⁀stat* contains a prius ĜUS⁀ 'tasting'; and *vastat*, from *vap⁀stat*, belongs with Av. *yasčā vāstrā vīvāpat* "und der die weideländer verwüstet" (*quique prata vastat*).

The texo-plec[s]t(h)o group in Latin; frequentatives.

77. In *va(p)s⁀stat* I see a relatively late combination (cf. Germ. *feststeht*) of a participial prius with *stat*. There was an earlier flexion type with STHO/E preserved, in a curiously compact semantic group, viz.: in Lat. *flecto, plecto, necto*, verbs meaning 'to plait, bind' or the like; also, as nobody has hitherto recognized, in *texo* from IE. TEK̄S⁀STHO 'I weave' ('I wattle')—a house; see Meringer Wört. u. Sachen 3. 52. In Latin *texo* : Skr. *tákṣati* T(H) was lost, perhaps by dissimilation with the initial T (ST-); but in Greek *τέκτων* 'builder, wattler' *-κτ-* is the due form for -KSTH-, as in *ἕκτος* '6th' : Skr. *ṣaṣṭhás*, cf. *-ct-* in *flecto, plecto, necto*. It is not to be determined whether in these words STHO/E meant 'to weave' (cf. e. g. Walde s. v. *stamen*), with an accusatival prius; or meant 'to stand', of the attitude of the weaver wattler twister, with an infinitival prius. There was always occasion, at the junctionpoint of compounds, for varying treatment of heavy consonant groups according to the semantic preponderance of one or the other member in the mind of the word-user. Note cases like *ἕκτος* : Lat. *sextus/Sestus*, OHG. *wast/wahst*. In the combination KST the unhampered product was KT, but KST, and subsequently KS or ST, are analogy or recomposition products. This seems to be proved by OBulg. *pletą*, with *t* from KT,[2] but infin. *ple[k]sti*[2] 'flectere'.

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[1] But *βαστάζω* contains an accusative *βάρ[ο]ς* + *στάζω* in transitive value = 'stands up, weighs', cf. *ἱστὸν στῆσαι* etc.

[2] For K not K̂ we must look to Lat. *plēcto* 'I beat', from a vriddhied noun *plēks⁀* 'beater' (cf. Lith. *plékiu* 'plēcto') + STHO/E; cf. *τύπτω*, same sense, 'I whip', noting Eng. *whip*, action noun, = 'driver'. The noun stem *plĕk* meant 'rod' or 'switch' (Lat. verber) as used in wattling or basket-making; also in beating, cf. Eng. *lashes* = 'plĕctit' (= binds with a lash) and 'plēctit' (= beats with a lash). In Skr. *praç-na-s* a K̂-final is found. Note the G-final in *πλάγιος* 'obliquus', *πλᾱγος* 'latus' (named from the 'basketry' of the ribs). Perhaps *praç-na-s* 'basket' (with *r* = L) is to be correlated with *praç-ná-s* 'question' (: Lat. *prec-es*), with *r* = R. The original *r*-stage is found in *πορκυς* 'fishing-net', *πόρκης* (Homer) 'band, hoop'. The *l* variety would be due to rhyme with the *flecto* sept. On the face

78. In Skr. *céṣṭati* 'stirs', *veṣṭate* 'wraps' we have frequentatives from K̑ĒI and WEI (see Uhlenbeck Wbch. s. vv.), or rather complexes with K̑EIS⁀ and WEIS⁀, nominatives, + STHO/E; but the conditions of the loss of aspiration are not clear. On the other hand, the aspiration lies clear to sight in *αἰσθάνω* 'I perceive', prius AIS (see on QU-AIS⁀ § 66), 'accipiens, capiens' (see Thes. Ling. Lat. for these as verbs of sense perception) + *σθάν-ω* (see on Lat. *dănunt* § 70). Is *ἁμαρτάνω* 'I miss' from N̥ + MṚK̑S⁀ (: Skr. *mṛçáti* 'touches') = non‿tangens + STHANŌ—with aspiration subsequently shifted to *ἁ-*? The frequentative note is not altogether vanished in *ἐ[δσ]σθίω*=edens‿sto; but *(Ϝ)εσ-θημένος* is a compound of *Ϝεσ-* 'vestis' with a participle of *τίθημι*. Cf. on *ἕν-νυμι*, 85.

IE. ARK(I)-STHOS '*cave-dweller*; *bear*'.[1]

79. The *texo* sept and the *ursus* sept constitute the best proof yet offered for -(K) þ,[2] but in *ἄρκτος*, as in *τέκτων*, *κτ* goes back to KSTH. I start from ARK-I-STHOS reduced to ARK-STHOS by gradation (§ 1, 3). The complex meant either 'ad arcendum stans', of the bear's posture in "hugging" (and so was eventually a "superlative"; see AJPh. 31, 409 sq.); or more likely 'in arce

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of it, 'question' and 'reed' (for plaiting) are not correlated concepts, but if one bethink himself of the sticks used in drawing lots (? or of the *cortina*, cf. Fay in Cl. Rev. 11, 298) the correlation may become evident. If, as Lobeck taught us, *ἀνεῖλε ἡ Πυθίη* (=respondit Sibylla) got its sense from the picking up of the lot-sticks, then the casting of those sticks was tantamount to proposing a question, making a petition. The Pythia played (*spielte*) jackstraws and worked *spells* with marked *spillikins* (? runic *buch-stäbchen*). On the non-Germanic cognates of Eng. *spell* see Fay AJGerPh. 6, 427. The prayersticks of the American Indians (see Handbook of Am. Ind. 2 s. v.) furnish a general analogy to the Pythia's spillikins. Note that as in jackstraws so in the game of jackstones children still keep alive the old games of divination.

[2] On -STHI as an infin. posterius see § 82. The retention of S in the group KSTH will have been due to the influence of the (separable) infin. suffix; on the tenacity of suffixal endings see Verner and Bartholomae, cited in AJPh. 33, 383.

[1] There is a curious censure of Arabic lexicographers (see Encyc. Brit. 24, 727) for putting down 'tearer' and 'mangler' as names for lion, because the poets have employed these words to describe the lion.

[2] Most of the material gathered in Brugmann's Grundriss^2 1, § 920 for *p* really shows complexes with STHĀ. (1) The *kṣi-ti-s* sept, meaning 'dwelling', is blended from the roots K̑ĒI 'to lie' and STHĀ 'to stand'. Lith. *ssei-mýnas* comes solely from K̑ĒI; OSax. *sethal* either has *s-* from KS[T]- (with dissimilation due to the following T?) or its *s-* comes from the *sedeo* sept. (2) Boeot. *ὄκταλλος* will owe its *τ* either to general irradiation from the parts of the body with STH (see Fay AJPh. 34, 23 sq. §§ 59–75) or to the specific note contained in *oculi stantes* (Ovid),—*eminentes* (Cicero). (3) In *κτάομαι κτῆμα* 'property' we may have to recognize a **τκάομαι* : Lith. *tèkti* 'to come in to one's possession'. (4) In *κτίλος* 'still' we have a blend of STHILOS and of some like derivative from the root of Lat. *quies-*, a root that looks, after all, to be cognate with K̑ĒI, with the palatal guttural. Perhaps the root was K̑(W)ĒI. For Lat. *silet* and Gothic *-silan* I recognize an initial group K̑(W)STH-.

stans', of the habitat of the cave bear. The arx was a mountain fortress or stronghold, originally a cave; cf. *arca* 'chest', *arcānus* 'secret', *arcera* 'covered wagon'. The further reduction in Lat. *ursus* (from R̥K[I]STHOS) would seem to show a double weakening before the accent, 1st of I, 2d of AR to *ṛ*. On Lat. *rs* from RKSTH see § 80. The shorter form in ἄρκος will have come, with haplology, from AR[KI]-K̂OS 'in specu cubans'; cf. Skr. *giri-ças* 'in monte cubans' with *giri-sthā́s*.

The past participle in -(S)T(H)OS.

80. If we start with an infinitive BHUDHÍ (suffixless BHUDH?) = Skr. *budhí* and add -STHOS, the complex BHUDH-I-STHOS, with loss of I before the accent (§ 1, 3), would yield Skr. *buddhás*; i. e., supposing S to have been lost in this or some other heavy consonant group. So KER[I]STHOS 'factus' would have yielded Skr. **kṛthás*, and UK^w[I]STHOS Skr. **ukthas*, and we actually do have *ukthám* 'carmen', a sacred word with retained TH. In Skr. *bhaktám* 'divisum' TH would reduce by Grassmann's law to *t*. From words like this the unaspirated suffix seems to have been generalized in Sanskrit, or even earlier in Indo-Iranian. In roots ending in -S, in such participles as Skr. *uṣṭá-s* : Lat. *ūstus*, Skr. *juṣṭá-s* : Lat. *gŭstus* (noun), the reduction, whether by haplology or before the accent, of ĜUS-I-STHOS to ĜU(S)STHÓS had led to the conception of the ending as -T(H)OS further to reinforce form-complexes like those represented in Skr. *bhaktá-s* and *ukthá-m*, wherein *s* had also been extruded from a heavy consonant group. Exceptions to Bartholomae's law like Av. *basto* : Skr. *baddhás* 'vinctus' (but *vərəzdå* : Skr. *vṛddhā́s* 'senes') may be due to the greater semantic prominence of -STHOS in a complex long felt as 'in vinculis stans'. In Latin participles like *mulsus, pulsus* (? cf. *census*) STH in the group of three or four consonants yielded *s*; cf. *ursus* (79) from R̥KSTHÓS. The passive force of the -STHOS complexes came from the infinitive prius. This is to interpret BHAG-I-STHÓS, say, by 'in‿dividendo (divisione) stans' and BHUDH-I-STHOS by 'in‿expergendo (vigilantia? or ad‿vigilantiam) stans'. Other complexes of the infinitive prius + STHOS yielded the superlative (see § 79). Sporadic exemptions from the generalization of -TO- rather than -ST(H)O- are to be recognized in ἄ-γνωστος (Odyssey) : Lat. *ignotus* and in Latin *pāstus* (prius the infinitive, not root, *pāi*, see § 4) : ἄ-παστος (which may be from PĂ[SI], like Lat. *dăre*, + STHOS) = non in‿edendo stans. In compounds (like ἄ-γνωστος, ἄ-παστος) archaisms of form or meaning are often retained.

The Aorist in -STHĀS (-STHĒ-S).

81. The forms *ἐ-γνώσ-θης* : Skr. *á-jñās-thās*, generally supposed to have drawn their S from the actives *-ἐ-γνωσ-ε á-jñās-am* (i. e. ĜNŌS⁀ + ĒSA, see § 18; on *-jnās ἄ-γνω(τ)ς* with passive sense from the reciprocal see Fay IF. 29, 418), may rather be *ἐ-γνώ-σθης*, with *-σθης* : Skr. injunctive *sthās* = Lat. *stas*.[1] The prius would be ĜNŌ[SI] (like Lat. *fāre* § 39) or ĜNŌI like Av. *vōi* (§ 4; cf. Gāthic *fra-xšnī*, Bartholomae Gr. Iran. Phil. § 260, 1) and the complex would mean ‘ad‿noscendum stas’. The loss of S- from (S)THĀS and its generalization to -THĀS would be analogous with the same loss in the past participles (80). Out of 10 random examples chosen by G. Meyer (Gr. Gram.^{3} p. 615) to exhibit the preponderance in Homer of *-θην* aorists over *-ην* aorists 5 would have lost S in the heavy consonant groups—unless in *διε-σχί-σθη* it was the *-δ* of the root that was lost. It is true that the proper Greek dialects certify Ē in the ending *-θην*, but this means that the vocalism of the *ἐ-μίγην* type (61) has preponderated. Note parallel Homeric forms like *μίγη/μίχθη*. As for the etymological character of *σθ* in *ἐ-γνώ-σθης*, it must be judged by the *st* of *nosti* (75) and the *στ* of *ἄ-γνωστος* (80).

Infinitive Complexes with -STHAI/-STHI.

82. Such complexes come clearly to light in Av. *bərəθe* and *bərəθi* (exx. in §§ 4, 69) from BHṚSTHAI/I, with S lost as in Skr. *caturthá-s* ‘4th’ (see AJPh. 33, 398 § 38, noting the haplology in *sapta-[s]thá-s* ‘7th’). The TH of *bərəθe* (cf. *ukthá-m* § 80) is certified by the TH of Skr. *bhṛthá-m* ‘res divina, sacrum’, while in *bhṛti-s* TH yielded *t* in the group THY (see Fay AJPh. 34, 15 § 42 a). In the Greek infinitive *φέρε-σθαι* (? prius BHERESI, like Lat. *regere*, +STHAI, with haplologic loss of SI) STH is also certified. The equation of Av. *dastē* ‘dare, facere’ with *θέσθαι* and *δόσθαι* is perfect, cf. OBulg. *plesti*, 77. I derive from participials DHES and DOS+STHAI. Of these, DOS appears in the Vedic compound (vocative) *draviṇo-das* ‘bonum‿dans’ with prius entirely like Lat. *facinus* in formation (85); cf. also nom. sg. *go-da-s* ‘bovi-dans’ in Manu. From such vocative use DOS became, by omission of the copula, an imperative; cf. Lat. *macte virtute* (*esto*). These forms DOS and DHES are also certified in the Skr. imperatives *dehí* and *dhehí*, wherein (D)HÍ is an optional or movable suffix omitted in *δός* and *θές*. The Skr. 2d pl.

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[1] Is it to the *ā* of the injunctive STHĀS that we owe the vocalism of *erās*, *-bās* (but see 69)?

mid. impv. ***dáddhvam*** shows the normal Sanskrit treatment of D(H)DH. Note the perfect equation (*ϝ* lost in the heavy consonant group) between *θέσθον* and Skr. ***dháddhvam***. It was because of *θέσθον* that *θέσθαι*, as well as some other *σθ* forms like *φέρεσθε* (69), was allocated to "middle" function. As for the impv. ending *-dhvam*, its *dhv* is to be connected with the *du* of Lat. ***per-duis***, ***creduas***, while its ***am*** is an accusative ending like the ending of λάβον (72 fn.). The restriction of the form to the 2d plural was due to pronoun forms like Skr. *vām* (really a precasual form, see § 50) : Lat. *vos*. It may be that ***dhvam*** is to be identified ultimately with the Plautine optional ***-dum*** with the imperative.

The middle person-ending -ME-DHI/-ME-(S)THA.

83. The IE. 1st pl. middle is represented by *-μεθα/-μέσθα* : Skr. ***-mahi***, Av. ***-maiδi***. Here we have, I think, two different combinations of the pronominal element ***me*** (: 1st sg. -MI) + DHI, the optional ending of the 2d sg. imperative just mentioned; while in the Greek endings we have ME + (S)THA, 2d sg. ending of *οἶσθα* etc. (75). Thus we better classify the facts than by calling the *σ* of *-μεσθα* a contribution from 2d plural in *-εσθε*.

The nasal conjugations: *complexes with* SNĒI '*ducere*'.

84. For some years past I have been studying tautological combinations and have especially applied this principle to the explanation of the nasal verb flexion (cf. AJPh. 25, 369–389; 26, 172–203; 26, 377–408; also Class. Rev. 20, 253 sq.; Cl. Quart. 3, 272 sq.; KZ. 42, 152 [*kṛṇóti*]; 45, 112 [Chinese tautological compounds]; AJPh. 32, 408 [Hungarian examples]; add Malay synonym pairs of loanwords, see Misteli l. c. 2, 237[1]). For the nasal verbs I supposed e. g. that Skr. ***badhnā́ti*** meant 'tie-binds' or the like. Note the pretty case of δείκ-νῦ-μι with δεικ⁀ = monstrator and *-νυ(ς)*⁀[1] = nutans.

85. By the examination of the Sanskrit root *nī* we may learn how (S)NĒI 'ducere, trahere' became fitted for use as a somewhat general auxiliary verb. This Sanskrit root means 'ducere, ziehen, trahere', and the intransitive senses of 'ziehen' (as to which see Paul Wbch.) are not extant in Sanskrit. But ***apa*** + ***nī*** = devestire and ***snā́yati*** = vestire, i. e. 'to draw on' (clothes), cf. Eng. ***drawers*** of the nether undergarments. Outside of Indo-Iranian the specialization of sense found in ***ducentes*** subtegmina or ***trahere*** lanam (vel-

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[1] Loss of *σ* in *-νυ(σ)τι* and *-νυ(σ)μι* as in BHERE(S)TI (70).

lera), *trāma* 'woof', prevailed and thus we reach the widely disseminated European root SNĒI/SNŌU 'to spin, weave' etc.; cf. *νεῖ νήματα* (Hdt.) with *deducit* aranea filum (Ovid). In Greek further specializations are found in *νηέειν ξύλα* = 'to draw (whence pile) logs' (cf. Bacch. 3, 33 *νᾰήσατο* = "rogum exstruendum curavit"); [cf. *στόρνυμι* 'I strew-pile']; *χείρεσσι νέων* = *pulling* (i. e. swimming) with his hands, cf. Skr. *nāvam* (with Ā,[1] though the object is cognate) *nayati* = navem *ducere* (i. e. to *pull*) and Germ. *ziehen* = 'to pull (a boat), remis ducere'; *νέομαι* (Homeric *νεῦμαι*) 'eo' (intransitive by ellipsis of the reflexive object, cf. Lat. *ago*, Germ. *ziehen* from *sich ziehen*). Gr. *νεῖαι νεῖται* (Odyssey) : Lat. *nis* 'nes' (Festus) are root flexion forms with the original diphthong, cf. Skr. *ne-mí-s* 'tire', i. e. 'inductum'. In Sanskrit *nī* was specially used for bringing to sacrifice (cf. the OLat. ritual question *agon*) attended by song (note *nītha-*); cf. the root *nāth-* (from SNĒ[S]TH § 76) 'to keep sacrificing', whence 'to beseech, precari', with Umbr. impv. *per-snimu* 'precator',[2] *persnis* 'precatus' from PERK⁀ 'precans' + SNĪTOS 'aditus, adductus' (deponentially taken) : Skr. [*s*]*nītā* 'ducta (in matrimonium)'.[3] The parallelism of the Skr. *nā* and *no* verb classes easily explains itself on the basis of composition with the root SNĒI / SNŌU. In *ζών-νυμι* and *ἕν-νυμι* we have the object nouns *ζως*⁀ and *Ϝες*⁀ + *σνῦ* : Skr. *snāyati* 'vestit'. For the noun object prius see Fay AJPh. 32, 408. In compounds like Skr. *vlī-nāti* 'crushes' : Lat. *vellit* 'pulls, plucks' the prius was *vlī* (cf. Av. *fra-xšnī* § 81) 'ad‿premendum'. In a verb like this, while we may still feel *nā/nī* as tautological, yet its force is scarcely more than the force of an auxiliary verb, ad‿premendum ducit = premit. The participle of *vlī* is *vlīná-s*; cf. Lat. *vellus* 'fleece', tautological from WEL + NOS, NOS meaning 'tractum' (cf. in Tibullus *tracta* = flocks of wool). This word NOS 'tractum', in the generalized sense of 'possessio', had a rich extension in the IE. tongues in such words as Skr. *áp-nas-*,

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[1] This Ā will be due to levelling between *NĒUS and its gen. NəW-OS.

[2] Or better define the verb according to 77 fn. by 'sortes (i. e. *preces* = spillikins) ducere'.

[3] In Skr. *saṁ-rā'j-nī* 'empress' we have in *-nī* either a cognate of *nītā* 'nupta' or else -GNĪ, another flexion form of *gnā* (: *γυνή*) 'wife' (of a god). For -NĪ we may cite *πότνα πότνια* (? originally 'potens‿ductrix'), but Lat. *regīna* looks like RĒG͡NĪ combined with RĒG͡NĀ, whence RĒG[N]I-NA, while the NI in Skr. *pátnī* may have come proethnically by irradiation from RĒG͡NI. On the basis of *rēgnum*, however, I decide for NĪ rather than GNĪ, for I see in the -NO- of *regnum* a derivative of NEI 'trahere' with the sense of Lat. *tractus* = domain. In Lat. *venenum* 'poison'—but doubtless first a love-potion only—we have the compound *wenes* + *sno-m*, clearly = 'amorem ducens'.

drávi-ṇas, ἄφενος, κτήνεα, Lat. *fenus*, *pignus* (further exx. in Meillet Mém. Soc. Ling. 15, 256), most of which either mean 'bona' or connote forms of property. It was from words like *vlīna-s* that the -NO- suffix of past participles was derived. As for Skr. *dráviṇas-*, its root will be found in δραίνεις (65), its type in *facinus*.

The buy-and-sell group; SNĒI *and* EI.

86. The formulaic usage of *nī* in Sanskrit is illustrated by the example *vi-krayaṁ nayati* 'mercatum ducit, vendit' (cf. *vi-kṛtiṁ nayati* = ad‿mutationem, sc. animi, ducit). Similarly *krī-ṇā-ti* 'buys' is made up of a locatival *krī* 'mercatum' (supine) + *nāti* 'ducit'. This leads to the interpretation of (ἐ)πριάμ-ην by PRI^{Y}M̥M⌒ + Ē(I)M; cf. with passive sense Lat. *vēn(um)ibat* : ὠν⌒έομαι, which comes from a locatival prius (cf. the Avestan noun locatives in § 4) Ϝωνει⌒ + ἐ(*y*)ομαι. In πρίῃ, πρίηται (subjunctives) we have a dat.-loc. infinitive πριῃ⌒ with copula omitted in 2d singular but represented by -Ē(I)TAI in the 3d. In (ἐ)-φερόμ-ην etc. we have an infinitive BHEROM + Ē(I)M (cf. on ἐμίγ-ης 61) 'ibam' or Ē(S)M 'eram'. True, ā is certified by the proper dialects, but its vowel color will be due to competing forms in -(σ)θην, before the analogy of the -ην aorists was submitted to (81). There was also a permanent competition of Ā and Ē in ἵστην and ἐτίθην.

Sanskrit-Latin gerundials from infinitive + NİYO.

87. The Sanskrit gerundives in *-enya-* have an infinitive prius + -NYO- '(se) ducens, ziehend'. Thus note in RV. 10, 120, 5 *prapáçyanto yudhé⌒nyāni bhū́ri* = prospicientes certamini‿ducentia (prize of combat, Griffith) multa and the common form *váre⌒ṇya-s* (note the conflicting accent and gradation of *yudhé⌒* and *váre⌒*) = ad‿optionem [se] ducens'. In the gerundives of the type of *karaṇīya-s* 'faciundus' I recognize *karam⌒*, weakened to *karm̥⌒* before *-nīya-* 'ad factionem (se) ducens'. The ultimate gerundial sense will have come from the infinitive prius (see e. g. Speyer VSS. 216 c; cf. also Bartholomae Wbch. s. v. *ah* 277, 3). Names like Lat. *Cupiennius Herennius* (cognate with Umbr. *heri* 'vult') look, Etruscan influence apart, to be of this formative type. On *-nn-* from -MN- in Latin see Fay Cl. Quart. 4, 87 sq. There is also nothing in the Italic dialects (v. exx. in Von Planta Gram. 1, 201 sq.) to prove MN from any of the *mn* combinations to be found there.

The agential suffix -TĒR/TŬR.

88. When Prellwitz, Wbch. s. v. *τείρω*, derives the agent suffix TOR from the root TER he is substantially right. It is a pity that he did not go further, however, and compare for its generalized sense of 'facere' OBulg. *tvoriti* : *tvorŭ* 'creatura, forma', which shows that the root is to be written TWER/TER. The strongest sort of evidence for the antiquity of the sense 'facere' results from the comparison of Slavic *po-tvorŭ* 'magic' with Skr. *kṛ́-tvarī-s*[1] (AV.) 'sagae'. After Jevons' discussion (see Anthropology and the Classics p. 98) of verbs of 'doing' in the sense of doing magic, the Whitney-Lanman note on *kṛ́-tvar-īs* (AV. 4, 18, 1), viz. that *kṛ́tvarīs* borrows a special sense from *kṛtyā́* 'magic', merely attests Professor Lanman's unconscious recognition of a first-class instance of tautological composition between the two roots of 'doing', KER and TWER—doubling perhaps their effect as what the American Indians would have called "medicine". In *kṛ́tvarīs* we find the tertium comparationis necessary to establish the correlation of *-tor* in Lat. *cultor* with *-tura* in *cultura* (with *u* from WĒ, see Fay AJPh. 34, 16 § 44 fn.).

89. Now Sanskrit also certifies to a stem-grade *-tŭr-* for the agent suffix, to-wit in *yantŭr-am* ("strong" acc. sg.) 'datorem'; cf. also the neuter *sthātúr* 'stativus' : *sthātár-* 'auriga'. Also in every agent noun genitive in *-tur* we have testimony to -TUR- + the genitive ending -[E]S (72). In the large group of adjectives in *-tur-* (nom. *-tūr*), like *aptúr-*, lit. 'opus faciens' but = 'operosus', we have further testimony to the "stem" -TUR- : -TOR/-TWER.[2]

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[1] I note in passing that masc. *kṛ́tvan-* 'faciens' exhibits dissimilation of *r- r-* to *r- n-* and suggests a source for the N/R variation found in *πίων*, fem. *πίειρα*, etc.

[2] The ending -TUR-O- appears in Lat. *satur* 'full', with sequel meaning from 'eater, having eaten'. All the Plautine usage reveals the connotation of 'gormandizing', e. g. Cp. 812, satur homost, habet profecto in ventre confidentiam; Poen. 804, extis sum satur factus probe; Mc. 750, non estis cenaturi? : : iam saturi sumus. The *Σάτυροι*, like their big-bellied leader *Σειληνός*, were probably merely *saturi*. Then the Doric title of *Τίτυροι* described the dancing satyrs, and is to be derived from the root T(W)ĒI : Lat. *quatio* (see Fay IF. 32); cf. Eng. *shake a leg* = dance. The root of *satur* was PSŌU (though cited by Hirt ap. Walde s. v. *satur* as SŌU-T), as Av. *fšav* 'fett machen', *fšao-nay-* 'feist' show, though the initial P was lost prior to Greek *ἀδην*. To the same root belongs Lat. *săgīna* 'fattening', with a secondary short *ă* (see Fay IF. 26, 32 and cf. Pedersen vglch. Kelt. Gram. § 126, 3, who notes the *Latin* shortening of pretonic *ā* in early Celtic loanwords). In *sagina* we have an infin. prius PSAI + *agīna*, cognate with *ἀγīνέω* (i. e. infin. AĞI + NEYO : Skr. *náyati*, cf. § 85), especially used of driving cattle, while Av. *fšav* explicitly means 'saginare'.

The Latin Desideratives in -turio.

90. The nominatives in *-tur* form a precious testimony for the Latin desideratives. Thus *esurio* is from **ēsur*, parallel with *esor* 'eater', and *parturio* is from a feminine **parturī* + *io*; cf. Skr. *iyati*, sporadic for *áyati* 'it'. Note the syllabic reduction in **păr(ĭ)tŭrī* as compared with *părĭtūra*. Aeolic μάρτυρ 'witness' (agent noun to the root in Lat. *memorat*, see § 58) gives further certification of -TUR and μαρτυρ⁀έω is nothing but μάρτυρ followed by the Greek flexion of EYO corresponding to the type of Skr. *áyati* (though ESO is phonetically admissible). The prius in Lat. *ligūrio* was the pf. ptc. (*ū* reduced from WŌ), unreduplicated like εἰδώς, but otherwise corresponding to Skr. *ririhvā̃ṁs*.

Latin centurio.

91. Applying the above analysis to *centurio* and writing a start-form **cent*[*um-t*]*urio* 'hundred-leader', we get a military term suggestive of Skr. *yantár-* 'marshal', *sthātár-* 'auriga'; cf. the compounds *pṛtsu-túr- ājí-túr-* 'in proeliis vincens', *viçva-túr-* 'omnia vincens', *su-pra-túr-* 'bene-pro-festinans', *ratha-túr-* 'bigas-celerans', *vṛtra-túr-* 'hostes-superans'. These words can leave no doubt of the belongings of τυρ- in τύρ-αννος.[1] In *centum-turio* the posterius *-turion-* is a tautological complex of TUR- ('vordringend zum kampfe' in RV.) + ĬYEN- (cf. Av. *ay-* in military usage, Bartholomae Wbch. 148, 4), nearly related to the "comparative" *tarīyas-* 'durchdringend' (cf. on the 'Υπερίων: Lat. *superior* type, Fay AJPh. 31, 424) and also to *turīya-* of the '4th' or "captain" (i. e. "princeps") finger (l. c. p. 426 § 63; 417 § 36).

The Latin passive; *quispiam sentences.*

92. After the demonstration of the grade -TUR- to the agent suffix -TŌR- the last obstacle is removed against the explanation of the Latin deponent-passive: *hoc mihi dator* (sc. *es sit*) came to be understood, thanks to the ellipsis, as *hoc mihi sit datum*. The same interpretation as a passive was also given to *hoc mihi datur*

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[1] I see in τύραννος a compound, prius TUR$\underset{\circ}{\text{M}}$, acc. sg. of an action noun meaning something like 'raid'; cf. Skr. *túr* quasi 'raider', *turí-s* 'überlegene kraft', *tū́r-* 'celeritas'. The posterius was -SNO- 'dux'; cf. SNĒI 'ducere', § 85. We have the same posterius in κοίρα-[σ]νος, which precisely corresponds with Germ. 'heerzog'. It is found again in Lat. *satellites* 'attendants on a king'. Here the prius is the agent noun KSA-TEL (see on the L-form of the TER suffix, Brugmann Gr.^{2} 2, 1 § 247) 'ruler': Skr. *kṣatrá-m* 'regnum', first compounded with (S)NO- 'dux' (cf. the modern title of *duke*); then **satellos* 'regidux' was affected by suffixal irradiation from *equites* and the like. Or SNES- : SNĒI- :: Skr. *dhas* : *dhā-*?

(sc. *est*)—wherein *datur* is like *esur⁀* in *esurio* (90). Words like *hortatur*, *hortator* (cf. also on *proditor*) remained in the voice of *auctor est* (5). In the Italic dialects (forms most conveniently collected in Dottin op. cit. 36 sq.) the 3d sg. and plur. forms end in *-tir*, i. e. the -TĒR of δοτήρ; in *-tur*, i. e. the -TŌR of *datōr*; in *-ter*, perhaps vocative to the -TĔR nominative; and in *-tar*, by samprasāraṇa from -TUR, which was Mommsen's explanation for the *-ter* forms (Unterital. Dial. 235, ap. Zimmer in KZ. 30, 277). In Umbrian the 3d sg. *ferar* will have been developed from 3d sg. act. **fera* (cf. *dirsa, teřa*) precisely as in Latin *feror* was developed from *fero*. The Umbrian 3d pl. futures (perfect) *benuso*, *couortuso* are plural nominatives, with loss of final *-r*, from the participles in *-us* (74); cf. the -ES- stem nominatives *tuderor/tudero*. The retained *-s-* of *benuso* will be due to the retained *-s* of *benus*: *benust* (73). Thus the forms like *benuso*[*r*] are precisely equivalent to **īyuṣ*[*as*] invoked above to explain Skr. *īyús* 'ierunt'. In Umbr. *ier* (not 'ibitur' but 'itum est', see the instance in Dottin 39) we have a precise equation with Av. **īyarᵊ* (72)—or with Skr. *īyús*. It is proper to mention here that Zimmer l. c. rendered *ier* by 'on va' (3d pl. active).

93. Into the Celtic forms I cannot explicitly go, but in his discussion of the Italo-Celtic deponent (KZ. 30, 224 sq.) Zimmer may be held to have demonstrated that this construction in Celtic properly belongs under the rubric of *quispiam*-sentences (mansätze), cf. his citation (p. 255) from O'Donovan's Irish Grammar: "For this reason some Irish scholars have considered the passive Irish verb to be a form of the active verb, expressing the action in an indefinite manner, as *buailtear me*, i. e. some person or persons, thing or things, strikes or strike me". What is that but this, that *hoc mihi datur* started with the sense 'hoc mihi quispiam dator est'?

The Latin Infinitive in -IER.

94. Over fifteen years ago in the Classical Review I offered an explanation of the old infinitives in *-ier* as containing in *-ie-* the present system suffix -(I)YE- and in *-r* an apocopated *-re*. To be sure of representing my actual meaning I quote a couple of sentences: "I propose to take the *-ie-* verbs as a starting-point, and so explain *de-ripier*' (Men. 1006) as an abbreviated infinitive to a *-ie-* stem. Thus *-rapier*, and rapere would belong, the first to a *-ie-* stem, the second to an *-e-* stem. It is common enough in Sanskrit for a root to have both *-ya-* and *-a-* present systems, and this state

of things appears in Latin also, at least with the verb *venio* (cf. Brix, Trin. 41)".

95. This passage has been curiously misunderstood by Stolz, who thus criticises it (Lat. Gram.^{4} p. 297): "Ganz ungerechtfertigt ist Fay's annahme eines Inf. *de-ripier* aus **de-ripiere* von einem *ie*-stamme (*rapere* soll der eines *e*-stammes sein!), vgl. . . . (IFA. 8, 209)".

96. Now I was trying to make a statement that would be clear to classical scholars not Sanskritists and impatient of comparative grammar; and having mentioned previously the pair *bibere/biber'*: *bibo* I thought that explaining *de-ripier'* : *deripio* would be the clearest way to state my point; and in speaking of the -IE- and -E- stems I had predominantly in view the Latin flexional system as stated in the non-comparative Lat. grammars. I looked for a scholar of Stolz's specialistic knowledge to interpret my meaning in the terms of his own science, but I see that I must have been enigmatic.

97. What I supposed then I suppose now, viz. that *-ripier'* came from a verbal noun RA^{x}PYES- and that *rapere* came from a verbal noun RA^{x}PES-. In Indo-Iranian there is no lack of such nouns in -YES- in infinitival function. Macdonnell's Vedic Grammar § 585, 1 gives *puşyás-e* 'to thrive', *sáhyas-e* 'to conquer', both in most obvious relation to their present systems, viz.: *púşyati* (with secondary accent for **puşyáti*) and *sáhyate* (classical passive; cf. *sahyāmi*). Note also *dhā́yas-e* 'to cherish' (: *dhā́yati* 'suckles'), *bhiyás-e* 'to fear' (: *bhā́yate* 'fears'), *çriyás-e* 'to be resplendent'. In the Avesta -ES- stems occur in a suffixless locative, and Bartholomae (Gr. Iran. Phil. § 260 a), after citing the suffixless Gāthic *avo* 'juvare', adds: "ferner aus praesensstämmen: Gāthic *vərəzyo* 'zu wirken'", with a cross-reference to the *ya*-class presents. For a locative ending in -ESI cf. Av. *pairi-tačahi* 'circumcurrere'. Let not Professor Stolz imagine that I am concerned whether the name infinitive be admitted for these Avestan forms or not. I am just as well content to call them verbal nouns. But I insist on the fact that both Sanskrit and Avestan verbal nouns attest the IE. forms dat. -YES-AI (? -EI), loc. -YES/-YES-I, evidently in some sort of relation to verbs with -(I)YE- flexion; and that these forms justify me in writing a pre-Latin *rapyes/rapyesi*, whence the form *-ripier'*. That its *-r* ending caused it to be interpreted as a passive, the infinitive being itself substantially of either voice at will (65 fn.), was noted sufficiently in my original paper. I may here add that *rapiē-bam* may be derived from *rapyes⁀fam* (but see § 43).

The Latin posterius -īvos.

98. In *nocīvus* (or *internecīvus*) I see an infinitive prius NOK̑-EI + (E)Ī̆-VOS, the pf. ptc. of 'ire' (72), if not EIVO-S: Skr. *éva-s* 'festinans'. We have a comparable formation in Lith. *neszė̃⁀yas* 'porter', i. e. 'portare‿iens'. In the forms like *nocuus* the posterius had the due grade -*oivos*. This is also the way to account for the *u* in *nocui* (see on *noc⁀eo* § 56), which will have had for its posterius in the complex not *Ī̆YAI (72), but a correctly graded perfect *OIYAI, like *οἶδα*. But it may be that *nociuos* is made up from a prius *nocĭ̄* 'nocere' + WOS, quasi '*manens*' (cf. § 40 fn.). If we assume a variant dissimilation of successive ST groups the morphological correlation of Lat. *statīvus* with the Skr. pf. ptc. *tasthivás*- presents little difficulty. With the *ī* of *statīuos* cf. the *ī* of Vedic (unreduplicated) *çvás-īvas*- 'snorting' (? ⏑ – ⏑ from ⏑ ⏑ ⏑). In *intempes*(*s*)*tīuos* the posterius is -STHĪWOS : STHĀI (cf. Fay AJPh. 33, 378, 4 sq.)

Appendix on Noun Flexion.

99. Analogous to the complexes that led up to thematic conjugation were complexes leading to thematic declension. Declension, like conjugation, consisted in the allocation of the infinitivals, suffixless and diphthongal, to the expression of the case relations. The cases were infinitives, but the infinitives were pre-casual, general locals, as in Bantu (50). The subsequent infinitive was an interjection, a call, a summons, an imperative. Take e. g. *ἄγει* as a summons "ad agendum', like the cry "ad arma". The development of the sense of leader, dux, *ἄγε*, Skr. *nāya* (with -E for -EI by § 1, 1), becomes perfectly transparent. It is all of record in Trimalchio's cry of *Carpe*, *carpe* (Petronius 36). [The gradual loss of the infinitivals, though not susceptible to proof, may perhaps be admitted. Note the paucity of infinitives in Classical Sanskrit as compared with the wealth of those formations in Vedic Sanskrit and Avestan. Herein Latin, say, runs with Classical Sanskrit. The elimination of the IE. free infinitives must have resulted from their gradual fixation first in formulaic complexes, then in grammatical forms.]

100. These calls with the diphthongs in -*ă̄i*, -*ĕ̄i*, perhaps -*ŏ̄i* (see § 103), formed the basis of thematic inflection. In the Indo-Iranian group -AI is preserved in the vocative of the -*ā* declension, ***kánye*** : *νύμφα* (see § 1, 1), possibly also in *γύναι*. Note besides the *ă* of **δέσποτα**, *agricola*, *collēga*, nouns earlier in type than the *ā*-gender; cf., with *ă̄i* or *ŏ̄i* diphthong, Lith. *tė́vai* 'pater'. Account is also to be taken

of the phenomenon known in Sanskrit grammar as *pluti* (cf. Wackernagel ai. Gram. I §§ 255–257), the prolongation i. e. of vocatival *-ă* to *-āʒa*, of vocatival *-e* to *-āʒya / āʒi.* I interpret *-āʒa* to mean the protraction of -Ē̆I.

101. The calling forms in -Ā̆I, -Ē̆I / -Ō̆I account at once for a number of the case forms. Taking **Musae* as a typical vocative, in a sentence like *tibi* **Musae donum est* we account for the interpretation as a dative; while *tibi* **Musaʒi factum est* reveals how the instrumental arose. When a noun like γῆ had passed from the sense of 'bearer' to the sense of 'earth', Terra, in a sentence like *tibi*, * *Terrae*, *vinum fundimus*, we realize how the vocative became a dative-local. With a "locative" infinitival like χειρ-ί, originally = 'ad‿prensandum,'[1] the functions of instrumental dative locative remained undifferentiated.

102. The summons in the diphthong infinitive, let us say **carpei*/ **carpoi* 'ad carpendum', when addressed to several, became a plural as in Greek -οι, or a dual as in Skr. feminine *kánye*, neut. *phále*; and these diphthong forms are earlier than the -ŌS -ĒS plural nominatives. In the name κλυται-μήστρη 'famosa‿comminiscens' we have in κλυται⁀ one of the early diphthong case forms, whence the later samdhi form κλυτᾰ′ (see § 1, 1), neuter plural.

103. From the precasual cries in -Ā̆I came the *-a* declension nouns like ῥοή 'flumen', for which Collitz (BB. 29, 81 sq.) has already rendered probable, in my opinion, the stem-form -ĀI (cf. the reduction feminine byforms in *-ī*, noting for this vowel stage Kretschmer as cited in §59). From cries in -Ō̆I, the vocatives like Πειθοῖ and 'Ηχοῖ. came the nouns in -ώ (cf. J. Schmidt KZ. 27, 369 sq.); and from -Ē̆I cries such nouns as Lat. *fidēs*, *caedēs*. The -I stems, known in Bartholomae's grammatical works as -ĀY stems, may be based on locatives in -I, unless -IS is pronominal like ES/OS (104).

104. The vocative must have long done duty as nominative also, but in the "vowel" declensions a nominatival -S arose, I surmise, as follows. After an original vocative like POTEI/POTOI 'domine' stood the demonstrative ES, as found in ESMI (48), whence by subsequent fusion POTEYES. A cry of the briefest type, e. g. ĜHER "ad prensandum", would have yielded ĜHER-ES, as in Skr. *hará-s* 'greifer, destroyer' but **hára-s* 'griff'. From ĜHER-ES ĜHEROS arose by deflection and finally, after -ĜHEROS came to be widely

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[1] Cf. OLat. *vola* 'hand', i. e. 'ad prensandum': the root of Skr. *vl̄nāti* (85).

used in composition, G̑HOROS. Two types now existed, a calling form G̑HER with a nominatival G̑HER-ES beside it, and a calling form G̑HER-Ē̆I with a nominatival G̑HEREY-ES. Of these, G̑HER-ES/G̑HOROS was finally allocated to the singular and G̑HEREY-ES to the plural, the one coming to belong, in course of time, to the -O declension, the other to the -I declension. To the latter was given a nom. sg. in -IS, wherein the demonstrative IS, parallel with ES, is perhaps to be recognized. The well-known interchange of the -O and -I stems in Latin, often distributed between the simplex and compound, may perhaps shed a glimmer of evidence into this glottogonic gloom.

105. The proof that the demonstrative ES came to be attached to a cry and converted it to a nominative can certainly not be rendered in the present state of our knowledge, but it is at least worthy of note that in pre-Semitic scholars have analyzed their extant nominatives in the same way, writing as a type, by way of explanation of the -U nominatives, **malik-hū* 'rex ille', see Brockelmann l. c. § 117 a. In Indo-European -S, and not -ES, came to be abstracted as the ending of the nom. sg. This I take to have been because, when G̑HER-ES was still spoken, G̑HERE, the samdhi form of G̑HEREI, came to be associated with G̑HER-ES as its vocative and, the difference being an -S, this was seized upon as the nominative formant.

106. As for the genitive "suffixes"[1] -ES (consonant) and -SO/-SYO (*o*-stems), it may be noted that SO is formally identical with the IE. article (n. sg. m.) and ES is also a demonstrable nominative (48). In the oldest Sanskrit we find *syás* alongside of *sá*(*s*). I suggest that a late Indo-European who said RĒG̑ES DOMOS was echoing an ancestor whose thought was RĒG̑ ES DOMOS 'king, the house'. The possessive relative was at first inferential merely, as in French in *la porte Saint Martin* (cf. Misteli op. cit. 2, p. 96). A still later Indo-European who said NEROS(Y)O DOMOS echoed ancestral NERO S(Y)O DOMO(S) 'man, the house'. Like the so-called stems used in composition, NERO and S(Y)O are forms prior to the adoption of nominatival -S (104).

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[1] In view of AJPh. 34, 237, this paragraph is respectfully offered for the consideration of Professor Gildersleeve.

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C. VERB-CONJUGATION.

a. A non-elliptical IE. verb form consists of a prius, which is either an infinitive (type Skr. *ā́stam—rán* = eratis—dando>dabatis, 38) or a participial (type *rex⁀erit* 7 sq.); and of a posterius, an auxiliary verb (of ultimately demonstrative origin 48) combined therewith. Incomplete and inconsistent regularization of the verbal paradigms in the various tongues 32 fn. 44; proethnic vs. ethnic analogy forms *ib.*; standard paradigms 54, 68–69.

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c. Thematic diphthong from EITI 56, 59; attested in 2d and 3d sg. *φέρεις φέρει*, in gradation with "optative" *φέροις* and Gothic indic. ***habais habai***, 2d and 3d dual (archaic) Skr. *bhdret(h)e*, cf. Lat. "optative" *velis* (ī <EI/OI) : Goth. indicative ***wileis*** 55; corresponding long diphthong forms in *φέρῃς* Goth. ***habáis*** Skr. *bravāite* (dual) 55.

D. *Surviving or revived periphrastic complexes.*

a. Flexion originated, ex hypothesi, in word groups, which remained long separable 17, 57. Skr. exx. of participles combined with forms of *as* 'esse', *sthā* 'stare', *i* 'ire', *car* '*πέλειν*' etc. 3; *āstam—ran* (in tmesi) = eratis—dare = dabatis 38; Av. exx. *θwōi ahī* = tueri (tuendo) es = tueris; *asti bərəθe* = est ferendo > fert, possidet, 69; *aēni bərəθi* = eam (i. e. ibo) ferre > feram 60; ptc. with forms of STHĀ 4; Greek exx. *βῆ φεύγων* and *βῆ δὲ θέειν* 2; with *ἱστάναι* 76 fn.; Latin exx. *balitantes eunt* 59–60; *sum solvendo* 4; *amatum iri*, cf. Skr. ***havītave*** 'sacruficare ire', *infitias ire* 60; ptcc. with *stare* 76 fn.

b. Skr. periphr. pf. contains a pres. ptc. + 'esse' etc. 19, 40 fn.; cf. Greek form in 72; Amharic "constructive" 72 fn.

c. Skr. periphr. fut. is agent noun in *-tā(r)* + *asmi*, identical with Lat. *auctor sum* type 5; cf. Horatian proditor sc. *sit* 5.

E. *Assumed prehistoric periphrases.*

a. With ESTI, cf. Skr. *bhdrasi*, and with EITI cf. *φέρεις* 44; with ESO ESES(I) in Lat. *rex⌢erit, lux⌢erit* 9, 11; *δειξ⌢*[ES]*ω*/*δειξ⌢ε(σ)ω* 14; Skr. *(a)dikṣ⌢[as]at* 14. The IE. futures with ⌢SYETI 37; in BH(W)ĪT(I) 40 (cf. 43 on the Lat. *-bam* forms). OBulg. infin. complexes with *-achŭ* from ĒSOM 42.

F. PRIORA OF IE. VERBAL COMPLEXES.

a. Are either participals (agent nouns) or infinitives (action nouns); uncertainty between these as in *κατα-κταν⌢έουσι* and *μεν⌢έω* 17; infin., not ptc., in Lat. *ama-bo* 40. These infinitives are "bases" 55 fn.

Participial prius.

b. *Gradation* in priora: prius a vriddhied nom. sg. in -s, as in *δεικς⌢*, in Lat. *dīx⌢is* = dicens‿sis, *duxis* = ducens sis, etc., 14, 21, 24; gunated in Skr. *dveṣ⌢* 'hating' 67; reduced to zero in Skr. *dikṣ⌢ dukṣ⌢* Lat. *caps⌢ raps⌢* 12–14; of Ē-grade in *rēgs⌢*, *ĕ*-grade in *cleps⌢* 10, 12; of deflected or *o*-grade in *moneo* 56, *doceo* 59, etc.

c. Prius an *accusative* in Skr. *çrad-dhe* 'cor dare', in Lat. *au(s)-dī* = aures‿dare; cf. Vedic *akṣī-dan* = oculos detis 38; in *ζών-νυμι* and *ἕν-νυμι* 85.

d. (?) Prius a ***nom. without** -s* in Skr. *aç-* 34, *θεν⌢έει* 37, *φέρ⌢εις* 57, 69; ***pet-*** in Lat. *peto* 66.

e. Prius a ***nom. in*** -s(s) in Lat. *quaes⌢* 66.

f. Prius a ***mute stem nom.*** in -s, type *ἐπίτεξ ἐοῦσα* 67; hence came by haplology the root conjugation of verbs, see § 67; Skr. *rdkṣ⌢ati* : *ἀλέξει* 67; ***rex⌢erit*** 7–8, ***lux⌢erit*** 9; in combination with STHO/E (76 sq.) TEK̑S in Lat. *texo*, the ***texo-necto*** group 77; [reduplicated mute stem prius, Skr. *cikits⌢* 'monstrans', cf. *pipas⌢* 'bibens' 28].

g. Prius a ***nom. in*** -S from a root ending in a ***vowel***, Greek *βης⁀*; hence came, particularly, the SKO/E conjugation 26–27, 52; G^{w}OS in Skr. ***gdcchati***: *βάσκε*, *δός*[ES]*κον*, *φάς*[ES]*κε*; Lat. ***pās⁀***[*es*]***co*** 26; ***gnōs⁀stī*** 75; cf., with mute stem, ***pṛ͡ks⁀*** in Skr. ***pṛcchdti*** 52; reduplicated iu *διδακς⁀*[ES]*κω* 52.

h. Prius a ***liquid stem*** *ἀγερς⁀* > *ἀγειρ⁀* 17, Lat. ***vels⁀ vers⁀*** 12.

i. Prius an -ES stem, 1st of agt. noun, *ψευδής⁀*[ES]*ω*; 2d of action noun, *μελης⁀*[ES]*ω* 18; (?) ***tegês⁀bam*** 43.

j. Prius an -I stem (nom. -IS) in Skr. (*a*)***vediṣ⁀***[ĒS]***am***, *ἠ̆δ*[*ις*]*ε*(*σ*)*α*, Lat. ***dediss⁀ēs*** 25; *εὐρίς*[ES]*κω* 26–27.

k. Prius an adj. -O stem (nom. -OS) in Lat. ***crud***[*os*]***⁀escit luc***[*os*]***⁀escit*** 27; with feminine in -Ā in Skr. (subj.) ***bharāsi*** 51, 69, cf. ***vesperascit*** 27; (?) prius a neuter BHER⁀ 69.

l. Prius an agent noun in -TUR (without -S) in *μαρτυρ⁀έω* 18, 90, Lat. ***ēsur⁀io***, feminine in -TURĪ in Lat. ***parturio*** 90; cf. agt. noun in -TŌR in Skr. ***dātā'smi*** 11, Lat. ***auctor sum***, ***proditor*** 5.

m. ***Number of the prius***: singular ousts plural in Skr. ***dātā'smas*** 'daturi sumus' 11, in Lat. ***rex⁀erimus*** 15 sq., 23.

n. Singular varies with plural in ***leg***[*es*]***⁀erimus***, interchanging with -***lex⁀-erimus*** 11.

o. Singular identical with plural in root nouns with long vowel, e. g. in the *βήσω* type 16.

p. Plural prius in Lat. ***expetessunt*** 67–69 K̂WES[ES]⁀IMOS 59; *ἀγγελ*[*ες*]⁀*έ*(*σ*)*ουσι*, *μεν*[*ες*]⁀ 17.

Infinitival prius.

q. General: on the suffixless locative 50 sq.; its gradual loss 99.

r. Monosyllables WEM⁀ 'vomere' 59, *θεν⁀* 38, *μένεω* 17; *θαν⁀οῦμαι* 27, *κατα-κταν⁀* 17, 27; Skr. ***vlī⁀nāti*** 85, cf. Av. ***fra-xšnī*** 81; Skr. ***dāi*** in ***dā-syati*** 'dabit' 39; STHA̯I in Lat. ***stābo*** 40 ĜNŪI in ***nōstī*** 75.

s. Dissyllables. (Vedic) in -***i*** 37, ***duhi*** 34, ***aç***(***ī***) in ***açīmahi*** 34, ***bravī*** in ***bravītu*** 60; ***naçi⁀ṣyati hani⁀ṣyati*** 37; ***vadhi⁀ṣṭa*** 'caedatis' 25; ***vart***(***i***)***syati*** 39; — with a diphthong, *ισται⁀ήτην* 61, *φερει⁀*[EI]*σι* 57, *μιγ*[EI] in *μίγη*; *μιγείη* 61; Lat. ***audī*** 38, 40, ****ad-ciyei*** in ***acciebo*** 40, ****pacei*** and ****proficei*** in ***paciscor proficīscor*** 27, ****sciyei*** (or ****sciyi*** ?) in ***scibit*** 40, ****tegei*** in ***tegēbat*** (?) 43; Balto-Slavic ***vidai*** (or -***oi***) in OBulg. ***vidě⁀achŭ*** 42; — with long diphthong in pre-Latin ***habēi⁀***[*ei*]***mos*** 56, cf. Goth. ***habdis*** 55; — in -OM in (*ε*)*φερόμ-ην* 86; in-***ām*** 65; in -(E)S-I in Skr. ***han***[*as*]***i⁀ṣyati*** (?) 37, ***dā***[*si*] ***syati*** 39; (*ἐ*)*γνώ*[SI]*σθης* 81.

G. ELLIPTIC FORMS.

a. By ellipsis of the auxiliary verbs the priora were themselves felt as finite verb forms 5; ellipsis with Skr. infinitive, Latin historical infinitive, cf. on ***agimini*** 6.

b. 1st sg. a dative infin. in -AI, Skr. ***duhe*** (pres.) Lat. ***videi*** (pf.): *οἶδα*[*ι*] 57; cf. Skr. ***vi-krī-ṇe*** 52; 2d sg. in -SAI, Skr. ***bhdr-as-e*** 57; 3d sg. in -EI, Skr. ***duhe*** (pres.) *οἶδε*[*ι*] (pf). 57. Note also 1st, not 2d sg., ***kṛ-ṣe*** in Skr. 57; 2d sg. in -***stha***(***i***) 75; 2d plural Skr. ***vida*** is also from an infin. in -A^{x}I, cf. Lat. ***agimini*** (6), 57. Similar infinitives are found in Balto-Slavic 2d sg. in -***ei*** 60, in Lat. ***nolī*** 56–57, cf. on 3d sg. *μέλει* 58; long diphthong in *φέρῃ* 58, *πρίῃ* 86; form in -(E)S-I in Lat. ***fare sequere*** 39; in -OM in *λάβον* 82.

c. Ellipsis with participial prius gives Skr. *rāṭ* 'regit' (regas) 20, 22; Skr. *dātā* = dabit 22; Lat. *proditor* sc. *sit* 5. The Latin passive, see *infra*; pf. ptc. prius as full verb form, Skr. *īyus* 72, Umbr. *benuso* 74, 92.

H. *The* EITI *conjugation.*[1]

a. Standard paradigm GʷHEN + -EIMI EISI EITI, pl. (E)ĬMOS (E)ĬTHE EYONTI/IYONTI 48, 68; (?) cf. *δραίν-εις* 65; also Ē(I)M Ē(I)S etc. in forms like *ἱσταί-ην* (*ἐ*)*μίγ-ην* 61, (*ἐ*)*φερόμ-ην* 86; cf. *πρίηται* 86, *ἱσται⁀ήτην* 61; Skr. -ĀIS -ĀIT endings 62; EYO EYES(I) EYET(I) flexion in *Ϝεμ⁀εω ζητέω doceo* 59, *moneo* 56, *queo nequeo* 59; in *amarēs* 61, *dedisses* 25.

b. Infin. *-īti* in OBulg. *nos⁀iti* 59; 2d/3d sg. *-īs -īt* 56, 59, 62; Skr. *abravīt* 60; -ĪTO, 3d sg. injunctive and ĪMAHI 1st pl, 34; ĬMOS in *dedimus* 74–75; 2d pl. -ITHA = 2d sg. in Skr. *ni-nay-itha* 'duxisti' 75; ptc. -ĬTOS in Lat. *sōpītus* : Skr. *svăpīta-s* 59.

c. -(I)YĒ- forms 31–32, 34, 36; Skr. *bhare-yā-tām* 61; (I)YONTI in Lat. *rudiunt* 59; ptc. stems EYONT- and IYONT- in Greek desideratives *κταν⁀έοντα ὀψείοντες κακκείοντες*, mid. IYOMENA in *πιομένη* 65; OIYAI in Lat. *noc-ui* 98; *ivi* in Lat. perfect 59, 66, 72 fn.; Lat. fut. *ībit* 40; Lat. desideratives in *-io*, type *esurio parturio* 89; cf. *ligūrio* 90; pf. ptc. of EITI in pre-Latin *ĭwŏs-/ĭyus-*, whence *ĭyos-/ĭwus-* 72.

I. *The* ESTI *conjugation.*

a. Based on living complexes like *ἐπίτεξ ἐοῦσα* 67; ESMI ES(S)I ESTI forms 48, 51, 69–70; -Ŏ(S)MI and -E(S)TI 70–71 (cf. Lith. *eĩ<s>te* 'itis' 70). Procope forms 's 'ST etc. 31, 51; 2d sg. *εἰς/εἶς* 44.

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BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
WILLIAM B. PHILLIPS, Director

THE FUELS USED IN TEXAS

BY

WM. B. PHILLIPS
AND
S. H. WORRELL

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INTRODUCTION.

The two most important things in Texas, in so far as concerns its material progress, are an abundant supply of cheap fuel and good water. Without these it is not possible to attain comfortable living or commercial prosperity.

Our reason for offering this publication on The Fuels Used in Texas is based upon the fact that while we have very large supplies of good and cheap fuel, we are not utilizing them to the best advantage. Our production of coal, lignite, natural gas, city and producer gas and petroleum does not begin to keep pace with current demands nor to promise well for the future.

The workable coal area in the State is 8200 square miles, with a possible addition of 5300 square miles. The original supply of coal was about eight billion tons. The production, since 1895, has been thirteen million tons, so that we have barely scratched the surface, so to speak.

The workable lignite area is 50.000 square miles, with a possible addition of 10,000 square miles. The original supply of lignite was about thirty billion tons. The production, since 1895, has been eight million tons, an insignificant fraction of the total.

The total fuel area, coal and lignite, is 58,000 square miles, with a possible addition of 15,000 square miles. The total original supply of coal and lignite was about thirty-eight billion tons, the total loss. including production and waste, has been, we will allow, forty million tons, or a little over 1 per cent of the total supply. If we mined twenty million tons of coal and lignite a year, instead of two million tons, the supply of these fuels would last more than 1000 years, allowing that for each ton used there was a total loss of two tons. It is true that, as compared with some other coals, our coals are not of the best quality; the seams are thin and the content of ash and sulphur is relatively high. At the same time many of these coals have been used with excellent results.

A special feature of the coal industry in Texas is that by far the greater proportion of the product is used for railroad purposes, only a small proportion going into domestic use.

Quite aside, however, from the coal, we have in lignite a cheap and efficient fuel for all kinds of industrial employment, with the possible exception of railroad locomotives. Practically every known variety of lignite exists in Texas, and in very large amounts. The lignite industry has increased at a very rapid rate, and with the attention now being given to improved methods of firing it is thought that a still larger increase may be expected, either in output or in efficiency, or both.

The time will come, if indeed it be not already come, when the establishment of large central power plants, using lignite as fuel, will present unusual attractions for investments of capital. The lignite will be converted into gas, either in producers or in retorts, and this gas will be sold for fuel purposes direct or converted into electrical energy and sold as such. From raw lignite there can be prepared a number of valuable products, in addition to the gas, as is set forth in Chapters X and XI.

If the lignite is distilled in retorts, one of the by-products is lignite residue, which makes an excellent material for high-grade briquettes, as is shown by Professor E. J. Babcock, Dean of the College of Mining Engineering, University of North Dakota, in Chapter IX.

The briquetting of lignite is not carried on in this State at all, but, in order to show what can be done, Professor Babcock kindly made for us a series of tests of these typical Texas lignites. The results were most encouraging, and our sincere acknowledgments are due to him for this timely assistance.

Through the courtesy of Mr. L. M. Davis, Minot, North Dakota, we are able to present a view of the lignite briquetting plant which he is now constructing there. This will be the only plant of the kind in the United States, and the results of its operation are awaited with a great deal of interest.

Our acknowledgment are also due to Mr. J. E. Stullken, Assistant Chemist to the Bureau, for much analytical work, and to Dr. W. Bredlick, who prepared Chapter X, assisted in the preparation of Chapter XI, and made the analyses of the coal tar given on pages 58-59.

We have also to thank Dr. Eugene A. Smith, Director of the Alabama Geological Survey, for analyses of Alabama coals.

We regret to say that a large number of analyses of Oklahoma coals, kindly sent to us by Dr. C. W. Shannon, Director of the Oklahoma Geological Survey, reached us too late for incorporation in this publication.

In connection with our work on the fuels of the State, the Legislature granted us a special appropriation, which will become available September 1, 1914. Plans are now being considered for the erection and operation of a modern steam-testing plant wherein a carload of fuel can be tried out at a time. It is hoped that particular attention can be given in this plant to lignite stokers and other appliances for increasing the efficiency of this and other fuels.

WM. B. PHILLIPS.
S. H. WORRELL.

Austin, Texas, December, 1913.

ORGANIZATION AND PUBLICATIONS OF THE BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY.

The Bureau of Economic Geology and Technology was established by the Board of Regents of the University, September, 1909. As there has been no geological survey in Texas for many years nor any agency through which there could be conducted investigations of the mineral resources, etc., of the State, it was hoped that the Bureau would be able to supply this deficiency, as far as was possible with the means at its disposal.

The laboratory of the Bureau was opened in September, 1910, with Mr. S. H. Worrell in charge. Since that time the demand for information, especially in connection with the purchase of fuels by the State Purchasing Agent and the University, has required the addition of another chemist, and Mr. J. E. Stullken was appointed in January, 1913. In September, 1911, Dr. J. A. Udden became geologist for the Bureau, and his first work was the preparation of the Report on the Oil and Gas Fields of Clay and Wichita Counties, published by the University, September 8, 1912, as its Bulletin No. 246, Scientific Series No. 23.

Exclusive of this bulletin the following publications have been issued by the Bureau:

The Mineral Resources of Texas, Wm. B. Phillips. Issued by the State Department of Agriculture as its Bulletin No. 14, July-August, 1910.

The Composition of Texas Coals and Lignites and the Use of Producer Gas in Texas, Wm. B. Phillips, S. H. Worrell and Drury McN. Phillips. University of Texas Bulletin No. 189, July, 1911.

A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, J. A. Udden, assisted by Drury McN. Phillips. University of Texas Bulletin No. 246, September, 1912.

A Map Showing the Location of Iron Ore Deposits in East Texas; Blast Furnaces; Lignite Mines in Operation; Lignite Outcrops; Producing Oil Fields, Etc., Wm. B. Phillips, September, 1912.

Eighteen Press Letters dealing with various features of mineral production in Texas.

A map showing the location of coal out-crops, coal mines, oil and gas fields, quarries of limestone and gypsum, deposits of copper ores, etc., in the area west and northwest of Fort Worth has been prepared, but has not yet been issued. Work on a geological map of the State is now in progress and we hope to have it ready for distribution by the close of the year 1914. There is no geological map of the State in existence and this attempt is the first that has been made to set forth the main geological formations throughout the State as a whole.

Field and chemical work for a special publication on the building materials mined and manufactured in the State is now in progress. This publication will include physical tests and chemical analyses of limestone, marble, granite, sandstone, serpentine, brick, hollow tile, etc.

All communications in regard to the work of the Bureau should be addressed to:

WILLIAM B. PHILLIPS, Director,
University Station, Austin, Texas.

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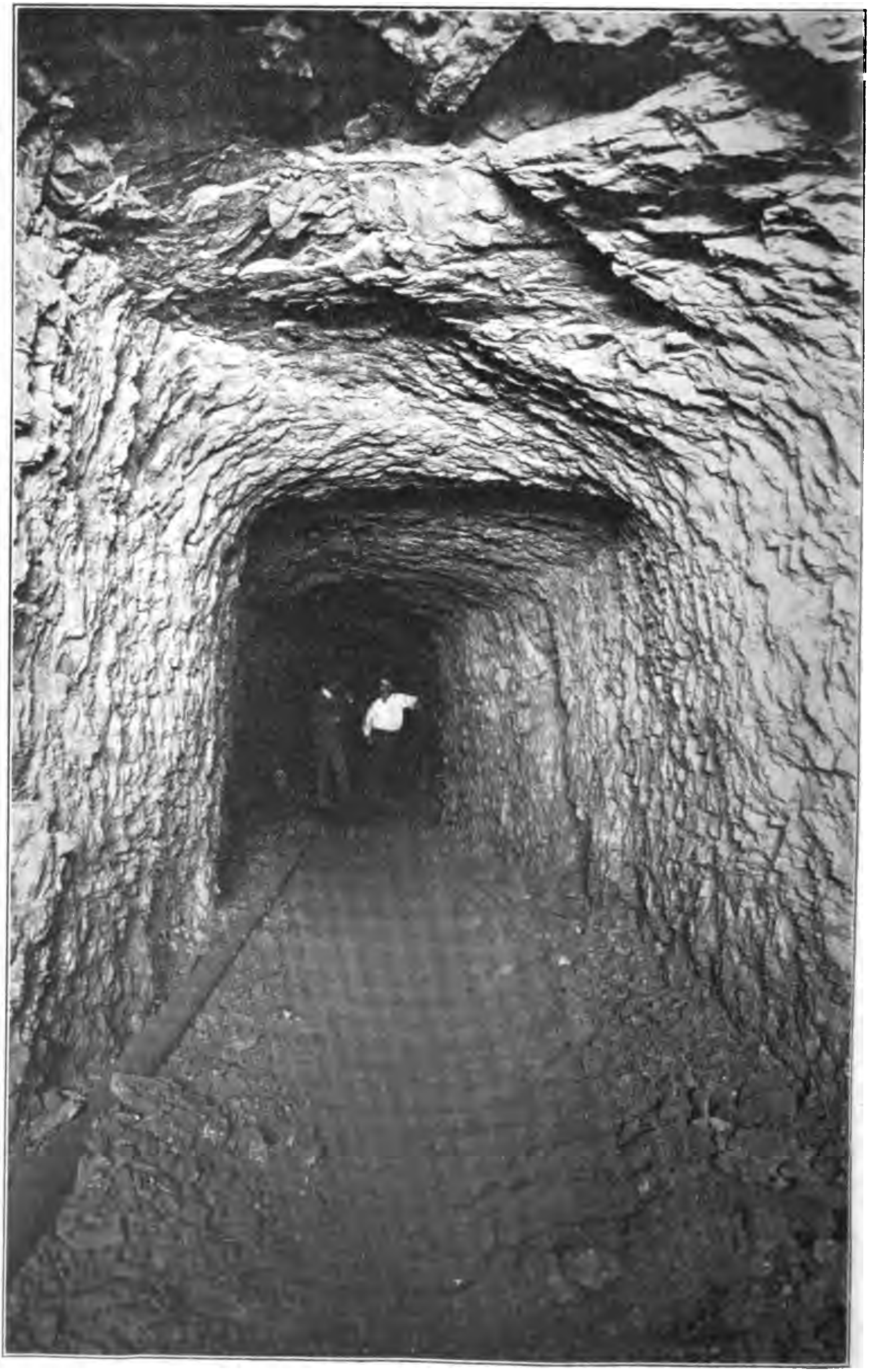

American Lignite Briquette Co., Big Lump, Milam County—Tunnel in 10-ft. of Lignite—2000 ft.

THE FUELS USED IN TEXAS

CHAPTER I.

BAGASSE (BEGASS, MEGASS) AND WOOD.

Bagasse is the name given to refuse sugar-cane after the juice has been extracted. It contains woody fiber, sugar juice and water. As a fuel under steam boilers it is used locally, but is of too low grade to be shipped to any considerable distances. We have no means of ascertaining how much of this material is used as fuel in Texas, but as the production of sugar-cane in the year 1912 was 400,000 tons there must be a good deal of bagasse made and used locally. We have not investigated this fuel but avail ourselves of a paper read before the Louisiana Sugar Chemists' Association, in 1892, by L. A. Becuel. We quote from this paper as follows:

"With tropical cane containing 12.5 per cent woody fiber, a juice containing 16.13 per cent solids, and 83.87 per cent water, bagasse of, say 66 and 72 per cent mill extraction, would have the following percentage composition:

	Woody fiber.	Combustible salts.	Water.
66 per cent bagasse	37	10	53
72 per cent bagasse	45	9	46

Assuming that the woody fiber contains 51 per cent carbon, the sugar and other combustible matters an average of 42.1 per cent and that 12,906 units of heat are generated for every pound of carbon consumed, the 66 per cent bagasse is capable of generating 297,834 heat units per 100 lbs. as against 345,200, or a difference of 47,366 units in favor of the 72 per cent bagasse.

"Assuming the temperature of the waste gases to be 450° F., that of the surrounding atmosphere and water in the bagasse at 86° F. and the quantity of air necessary for the combustion of one pound of carbon at 24 lbs., the lost heat will be as follows: In the waste gases, heating air from 86° to 450° F., and in vaporizing the moisture, etc., the 66 per cent bagasse will require 112,546 heat units, and the 72 per cent bagasse 116,150.

"Subtracting these quantities from the above, we find that the 66 per cent bagasse will produce 185,288 available heat units per 100 lbs., or nearly 24 per cent less than the 72 per cent bagasse, which gives 229,050 units. Accordingly, one ton of cane of 2,000 lbs. at 66 per cent mill extraction will produce 680 lbs. bagasse, equal to 1,259,958 available heat units, while the same cane at 72 per cent extraction will produce 560 lbs. bagasse, equal to 1,282,680 units.

"A similar calculation for the case of Louisiana cane containing 10 per cent woody fiber, and 16 per cent total solids in the juice, assuming 75 per cent mill extraction, shows that bagasse from one ton of cane contains 1,573,956 heat units, from which 561,465 have to be deducted.

"This would make such bagasse equivalent to nearly 92 lbs. coal per ton of cane ground. Under fairly good conditions, 1 lb. coal will evaporate 7½ lbs. water, while the best boiler plants evaporate 10 lbs. Therefore, the bagasse from 1 ton of cane at 75 per cent mill extraction should evaporate from 689 lbs. to 919 lbs. of water. The juice extracted from such cane would under these conditions contain 1,260 lbs. of water. If we assume that the water added during the process of manufacture is 10 per cent (by weight) of the juice made, the total water handled is 1,410 lbs. From the juice represented in this case, the commercial massecuite would be about 15 per cent of the weight of the original mill juice, or say 225 lbs. Said mill juice 1,500 lbs., plus 10 per cent equals 1,650 lbs. liquor handled; and 1,650 lbs. minus 225 lbs., equals 1,425 lbs., the quantity of water to be evaporated during the process of manufacture. To effect a 7½ lb. evaporation requires 190 lbs. of coal, and 142½ lbs. for a 10-lb. evaporation.

"To reduce 1,650 lbs. of juice to syrup of, say 27° Baume, requires the evaporation of 1,170 lbs. of water, leaving 480 lbs. of syrup. If this work be accomplished in the open air, it will require about 156 lbs. of coal at 7½ lbs. boiler evaporation, and 117 at 10 lbs. evaporation.

"With a double effect the fuel required would be from 59 to 78 lbs., and with a triple effect, from 36 to 52 lbs.

"To reduce the above 480 lbs. of syrup to the consistency of commercial massecuite means the further evaporation of 225 lbs. of water, requiring the expenditure of 34 lbs. of coal at 7½ lbs. boiler evaporation, and 25½ lbs. with a 10-lb. evaporation. Hence, to manufacture one ton of cane into sugar and molasses, it will take from 145 to 190 lbs. additional coal to do the work by the open evaporator process; from 85 to 112 lbs. with a double effect, and only 7½ lbs. evaporation in the boilers, while with 10 lbs. boiler evaporation the bagasse alone is capable of furnishing 8 per cent more heat than is actually required to do the work. With triple-effect evaporation, depending on the excellence of the boiler plant, the 1,425 lbs. of water to be evaporated from the juice will require between 62 and 86 lbs. of coal. These values show that from 6 to 30 lbs. of coal can be spared from the value of the bagasse to run engines, grind cane, etc.

"It accordingly appears that with the best boiler plants, those taking up all the available heat generated, by using this heat economically the bagasse can be made to supply all the fuel required by our sugar-houses."

FIREWOOD.

In Forest Service Circular No. 181, United States Department of Agriculture, issued September 23, 1910, the amount and value of the firewood used in 1908, in Texas, is given in considerable detail. The amount so stated is in cords of 128 cubic feet.

	Quantity—cords.	Value.
Used on the farms	2,518,360	$6,549,939
Cities and townsof from one to thirty thousand population	1,351,360	5,310,845
Cities of over 30,000 population	179,333	923,015
Mineral operations	55,933	176,507
Total	4,104,986	$12,960,306

This gives an average value per cord of $3.16.

In the total consumption of firewood, Texas ranks sixth among the States, the largest consumption being in the State of North Carolina. In the total value, Texas stands second; being exceeded only by Michigan. In average value per cord, Texas ranks thirty-fourth among the States. The highest price paid for wood was $8.99, in the District of Columbia, and the lowest value was in Georgia, $1.66 a cord.

In the year under consideration, namely, 1908, the quantity and value of the firewood used in the United States is stated as follows, in cords and dollars.

	Quantity—cords.	Value.
Used on the farms	69,961,066	$182,653,869
In towns and cities of from 1,000 to 30,000 population	12,611,033	50,549,855
In cities of over 30,000 population	1,613,594	11,106,526
In mineral operations	1,751,115	5,530,478
Total	85,936,806	$249,840,728

This gives an average value per cord for the entire country, of $2.91.

The heating power of well seasoned wood, expressed as British thermal units per pound, varies from 7,584 in willow, to 9,153 in some varieties of pine.

The following table partly compiled and partly made up from our own analyses, gives the British thermal units per pound of different varieties of wood:

Variety of Wood.	British thermal units per pound.
Ash	8,480
Birch	8,586
Cedar	9,507
Chestnut	8,338
Cottonwood	9,040
Cypress	9,429
Dogwood	8,806
Elm	8,510
Fir	9,063
Hickory	8,728
Maple	8,650
Mesquite	8,650
Mulberry	8,027
Post-oak	8,416
Oak, other ... from	8,316 to 8,440
Pine, bastard	8,759
Pine, long leaf yellow	9,118
Pine, spruce	8,962
Poplar	8,541
Sycamore	7,762
Willow	8,463

Relative Value of Wood and Coal, as Fuels.

Some authorities[1] state that one pound of good soft coal is equivalent to 2.50 pounds of air-dried wood. On this basis, a cord of pine wood, weighing on the average 2,600 pounds, is equivalent to 1,040 pounds of coal; a cord of hickory, with an average weight of 4,100 pounds, is equivalent to 1,640 pounds of coal; a cord of oak with an average weight of 3,550 pounds is equivalent to 1,420 pounds of coal; a cord of cedar, 2,500 pounds, is equivalent to 1,000 pounds of coal and a cord of mesquite, 3,000 pounds is equivalent to 1,200 pounds of coal.

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[1] Amer. Civil Eng. Pocketbook, 1911, p. 211.

These figures are of general value only, for a great deal depends on the boiler setting, grate installation, method and rate of firing, size of the wood, etc., in actual practice. As a rule, however, the proportion of 2.50 pounds of wood per pound of coal is reasonably accurate.

The relative cost of burning wood and coal depends upon a number of conditions, and each question has to be settled upon its own merits. If we allow that the cost of handling, firing and removal of ashes. is the same for the two fuels, coal at $5.00 a ton is equivalent to ordinary oak wood at $3.54 a cord, or pine at $2.60 a cord. With coal at $8.00 a ton, oak wood should be at $5.67 a cord, and pine at $3.20. In many of the towns and cities of the southwest, especially in Texas, these prices are current with respect to coal and oak wood; but inferior wood, such as cedar, cottonwood, willow, etc., is often sold at the same price as oak or mesquite.

As a rule, current practice in regard to the relative price of wood and coal, brings about a rough approximation to their respective values as determined by scientific investigation. When coal sells for $8.00 a ton, good oak wood sells for $5.50 to $6.00 a cord.

Weight of a Cord of Wood.

It is difficult to make a positive statement as to the weight of a cord of wood. Ordinarily, a cord contains 128 cubic feet. It is 4 feet high, 4 feet wide and 8 feet long. But in Michigan, a "cord" is 48 cubic feet and in California a "stack" (cord) contains 32 cubic feet. In Germany, the klafter, or cord, contains 108 cubic feet. But the ordinary cord lacks a great deal of containing 128 cubic feet of wood. The air space in a cord of wood may comprise as much as 25 per cent of the space, especially if the wood is crooked. If the wood is straight, accurately cut, evenly and well split and piled with care, the air space is reduced to a minimum but is never entirely removed. In his own practice, the writer has allowed as much as 160 cubic feet to be a cord, especially in dealing with crooked mesquite wood for quicksilver furnaces.

The amount of water in wood has a material bearing on the weight of a cord. If we allow that a cord of ordinary dry oak wood weighs 3,500 pounds and contains 25 per cent of water, the "wood" in the cord weighs 2,625 pounds and the water weighs 865 pounds. If a cord of pine wood weighs 2,500 pounds and contains 25 per cent of water, we have 1,875 pounds of "wood" and 625 pounds of water.

The weight of a cord of wood is not of much commercial importance, as the ordinary practice the country over is to purchase wood by the cord, irrespective of its weight or of its heating power.

When wood is shipped by rail it is not customary to weigh the car, but the shipment is made on a measurement basis, so many cords to the car. There is, of course, a considerable difference in the number of cords that can be placed in or on a car, and no general rule can be given. The number of cords in a car varies from 8 to 15, and, in exceptional cases, even more.

Kent[1] gives the weight of a cord, 128 cubic feet, of seasoned wood, in pounds, as follows:

Variety of Wood.	Pounds per cord.
Beech	3,250
Chestnut	2,350
Elm	2,350
Hemlock bark	2,200
Hickory	4,500
Maple, sugar	4,500
Oak, black and red	3,250
Pine, white or Norway	2,000

Poole[2] gives the weight of a cord of wood as follows, in pounds:

Variety of Wood.	Pounds per cord.
Ash, white	3,450
Beech, white	3,236
Butternut	2,534
Cedar, red	2,525
Chestnut	2,333
Dogwood	3,643
Hickory, shell-bark	4,469
Magnolia	2,704
Maple, hard	2,878

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[1] Mech. Engrs. Pocketbook, 1908, p. 232.

[2] Calorific Power of Fuels, 1907, p. 87.

Variety of Wood.	Pounds per cord.
Maple, soft	2,668
Oak, black	3,254
Oak, chestnut	3,955
Oak, red	3,254
Oak, white	3,821
Pine, New Jersey	2,137
Pine, pitch	1,904
Pine, white	1,868
Pine, yellow	2,463
Poplar, Lombardy	1,774
Poplar, yellow	2,516
Sycamore	2,391
Walnut, black	3,044

Snow[8] gives the following figures as the weight of a cubic foot of seasoned wood, in pounds:

Variety of Wood.	Pounds per cu. ft.
Ash	39 to 40
Beech	42 to 45
Birch	35 to 37
Cedar	19 to 35
Chestnut	28 to 36
Cottonwood	23 to 24
Cypress	20
Dogwood	50
Elm	34 to 46
Fir	36
Hickory	44 to 56
Linden	28
Maple	26 to 43
Mesquite	47
Oak	40 to 59
Pine	22 to 43
Poplar	26 to 28
Spruce	21 to 36
Sycamore	30 to 35
Walnut, black	38
Willow	27

The weight of a cubic foot of lignum vitae varies from 71 to 83 pounds.

Amount of Ash or Mineral Matter in Wood.

The amount of ash in wood varies from 0.11 per cent as in some varieties of oak, to 8 per cent as in some varieties of fir. As a rule, the amount of ash in wood rarely exceeds 2 per cent of its weight, and consists of lime, magnesia, potash, soda, the oxides of iron, manganese and aluminum as bases, combined with carbonic acid, sulphuric acid, silicic acid, phosphoric acid and hydrochloric acid, to form carbonates, sulphates, silicates, phosphates and chlorides.

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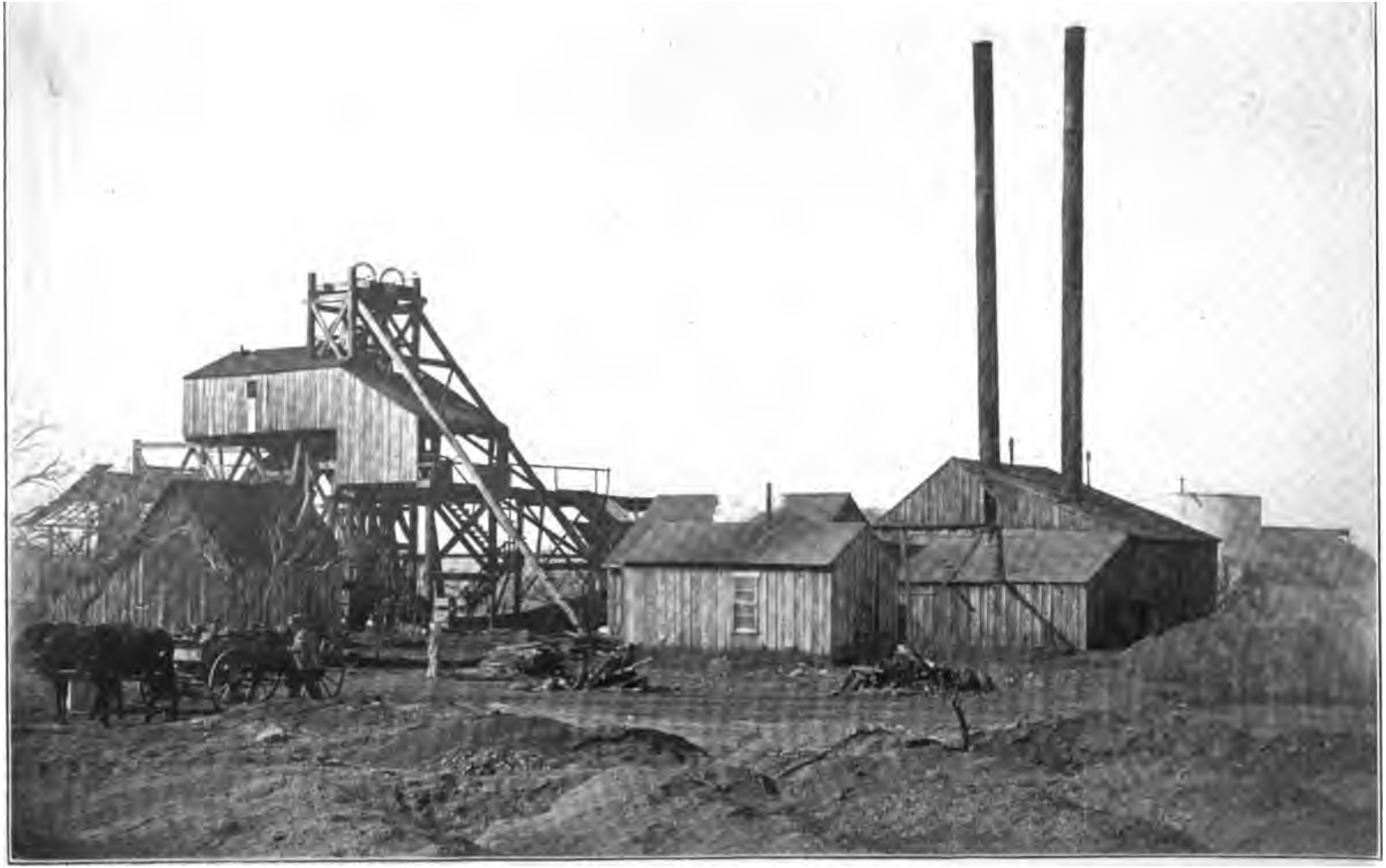
[8] Principal Species of Wood, 1910.

The ash of Scotch fir (pinus sylvestris), common in the British Islands and throughout northern Europe, may contain as much as 18 per cent of oxide of manganese, with 16 per cent of soda, and 5 per cent of phosphate of iron. The ash of some varieties of northern beech (fagus sylvatica) contains nearly 16 per cent of potash.

Amount of Water in Wood.

Ordinary, well seasoned wood may still contain 25 per cent to 30 per cent of water, and this water is not entirely removed up to 240° F. The proper age at which to cut wood for fuel varies from twenty years as in the case of alder to 120 years in the case of white beech.

As the population of the State increases and more and more demands are made on the supplies of firewood, we shall reach a time when we shall be obliged to look to some other source of fuel. In a great many parts of the State now there is no wood at all. The heavily wooded areas in East Texas will, of course, continue to supply a large amount of wood for many years, but we think that the cities and the larger towns will increase their consumption of coal and use less and less wood, as time goes along. It is likely that the practical efficiency of wood as a fuel is considerably below that of coal, but there are no investigations on this subject to which reference may be made.



Belknap Coal Co., mine No. 2, Newcastle, Young County.

CHAPTER II.

COAL.

COMPOSITION OF COALS MINED IN TEXAS.

Location and Extent of Coal Fields, Production, Etc.

In Bulletin No. 3, University Mineral Survey, May, 1902, there were given many detailed analyses of the coals and lignites then mined in Texas. The samples were taken in person by an agent of the Survey and represented the freshly mined material.

The edition of that bulletin was soon exhausted, and as the Survey was discontinued in 1905, nothing further was done until 1911. In this year there was prepared by the University Bureau of Economic Geology and Technology a bulletin on "The Composition of Texas Coals and Lignites and the Use of Producer Gas in Texas," and it was published by the University as its Bulletin No. 189. The edition of this bulletin has also been completely exhausted, so that it has become necessary to prepare another publication on the subject.

To the material which was published in 1911, we have added much new data dealing with the suitability of our coals and lignites for gas making and the recovery of valuable by-products. It is not our purpose to discuss the coal and lignite fields of Texas from a geological standpoint.

With respect to coal it is sufficient to say that there are three recognized coal fields in Texas, one in north central Texas, west of Fort Worth, and two on the Rio Grande. The North Central Coal Field lies in the counties of Brown, Coleman, Comanche, Erath, Eastland, Jack, McCulloch, Palo Pinto, Parker, San Saba. Shackelford, Stephens, Wise and Young. It comes south of the Colorado river in McCulloch and San Saba counties. Its coal is of Carboniferous age and sub-bituminous quality. It is entered by the following railroads: Texas & Pacific; Texas Central; Chicago, Rock Island & Gulf; Fort Worth & Denver; Fort Worth & Rio Grande (Frisco); Gulf, Colorado & Santa Fe; Wichita Falls & Southern; Mineral Wells & Northwestern; Stephenville, North & South

Texas; Gulf, Texas & Western. It produces by far the greater proportion of the coal raised in Texas, one county alone, Erath, yielding more than 50 per cent of the entire output of the State.

The seams of coal are not thick, no single bench running to more than 24 inches. Nearly all of this coal is used for railroad purposes, the remainder going to stationary boilers. But little of it is used for domestic fires. The coal producing counties in the North Central Field are: Eastland, Erath, Palo Pinto, Wise and Young.

No coke is made from any of these coals, although some of them are capable of yielding a coke of fair strength, but high in ash and comparatively high in sulphur. No attempt has been made to wash these coals in a modern plant and it appears probable that the loss in coal would be excessive, as there is not much difference between the density of the coal and the non-coal.

There are two other producing coal fields in Texas, both of them fringing the Rio Grande; one in Webb county (Laredo) and one in Maverick county (Eagle Pass). The Webb county field extends also into Dimmit and Zavala counties, but there are no commercial operations in these counties. The coal is probably of Cretaceous age, although some lower Tertiary strata appear to be involved also. It is sub-bituminous in quality. The Rio Grande coal fields are entered by the following railroads: Southern Pacific; International & Great Northern; Rio Grande & El Paso; Uvalde & Crystal City; Asherton & Gulf; Texas Mexican. The total workable coal area in Texas may be taken at 8,200 square miles, with an additional area of 5,300 square miles, that may contain workable beds, as estimated by Mr. M. R. Campbell, of the United States Geological Survey. The original supply of coal in Texas is thought by Mr. Campbell to have been 8,000,000,000 tons. The total loss of coal, due to production and waste, certainly has not exceeded 15,000,000 tons, so that we have still 99 per cent of the original supply left. This supply is sufficient to provide for a mining loss of 10,000,000 tons a year for 800 years.

According to the statistics collected by the United States Geological Survey for the year 1912 there were employed in the coal and lignite mines in Texas 5,127 men, who worked an average of 230 days. In 1910, there were 5,353 men who worked 226 days. In 1912 the coal mines employed 3,518 men for an average of 230 days and the lignite mines employed 1,609 men for 191 days. The average coal production per man was 340.5 tons, or 1.37 tons per working day. The average lignite production per man was 615.7 tons, or 3.22 tons per working day.

There is but little machine-mined coal produced in Texas, the amount in 1912 being 105,400 tons, or 4.8 per cent of the total. Shooting from the solid is not much practiced in Texas. While the mining methods reported account for less than one-half of the total production, the percentage of coal shot from the solid was but 25 per cent of the total, in 1911.

There is one coal washery in Texas, operated by the Olmos Coal Company, Eagle Pass, Maverick county. In 1912 this company washed 25,599 tons and recovered 20,639 tons of washed coal, with 4,960 tons of refuse.

The fatal accidents in 1912 were two, of which one occurred in the shaft and one on the surface. This is probably the lowest death rate in the entire country.

Separate statistics of the production of coal and lignite cannot be given with accuracy prior to the year 1895. Up to that time, beginning with the year 1884, the total production of coal and lignite was 1,943,500 short tons, or an average for the eleven years of 176,681 tons a year. Beginning, however, with the year 1895, we have coal and lignite as separate items.

The following table gives the production and value of the coal and lignite from 1895 to 1912 inclusive. The statistics are those of the United States Geological Survey.

TABLE I.

Production and Value of Coal and Lignite, 1895-1912—Short Tons.

Year.	Coal.		Lignite.	
	Tons.	Value.	Tons.	Value.
1895	360,616	$801,230	124,343	$111,908
1896	376,076	747,872	167,939	148,379
1897	422,727	792,838	216,614	179,485
1898	490,315	968,871	196,419	170,892
1899	687,411	1,188,177	196,421	146,718
1900	715,461	1,350,607	252,912	231,307
1901	804,798	1,655,736	303,155	251,288
1902	696,005	1,326,155	205,907	151,090
1903	659,154	1,289,110	267,605	216,273
1904	774,315	1,652,992	421,629	330,644
1905	809,151	1,684,527	391,533	284,031
1906	839,985	1,779,890	472,888	399,011
1907	940,337	2,062,918	707,732	715,893
1908	1,047,407	2,580,991	847,970	838,490
1909	1,112,228	2,539,064	712,212	602,881
1910	1,010,944	2,397,858	881,232	763,107
1911	1,083,952	2,491,361	890,641	781,927
1912	1,197,907	2,774,956	990,705	880,788
Total	13,367,635	$28,795,998	8,041,940	$7,153,824

Since 1895 the production of coal has increased by three times. During the same period the production of lignite has increased by nearly eight times.

The average value of the coal in 1911 was $2.30 a ton, at the mines, while that of lignite was 88 cents, these figures for 1912 being $2.31 and 89 cents, respectively.

These average values per ton are to be accepted with some reservations. During the last year, for instance, mine-run lignite has sold as high as $1.40, while lignite slack has been in active demand at 60 cents.

Composition of Texas Coals.

In 1901-1902 an agent of the University Mineral Survey was sent to all of the coal mines for the purpose of securing fair samples of the coal as mined. These samples were placed in sealed cans and sent to the laboratory of the survey. Detailed analyses were made, with particular attention to the percentage of moisture in the coal as mined.

The samples came from the following properties:

No. 1518. Rio Grande Coal Co. Minera, Webb county.

No. 1519. Cannel Coal Co. Darwin, Webb county.

No. 1520. Maverick County Coal Co., Eagle Pass, Maverick county.

No. 1521. Rio Bravo Coal Co., Eagle Pass, Maverick county. ✓

No. 1522. Wise County Coal Co., Bridgeport, Wise county. ✓

Nos. 1523-1524. Bridgeport Coal Co., Bridgeport, Wise county. ✓

Nos. 1525, 1526, 1527. Texas Coal & Fuel Co., Rock Creek, Parker county.

No. 1528. Young Mine, Keeler, Palo Pinto county.

Nos. 1529, 1530, 1531, 1532. Texas & Pacific Coal Company, Thurber, Erath county. ✓

No. 1533. Strawn Coal Mining Company, Strawn, Palo Pinto county. ✓

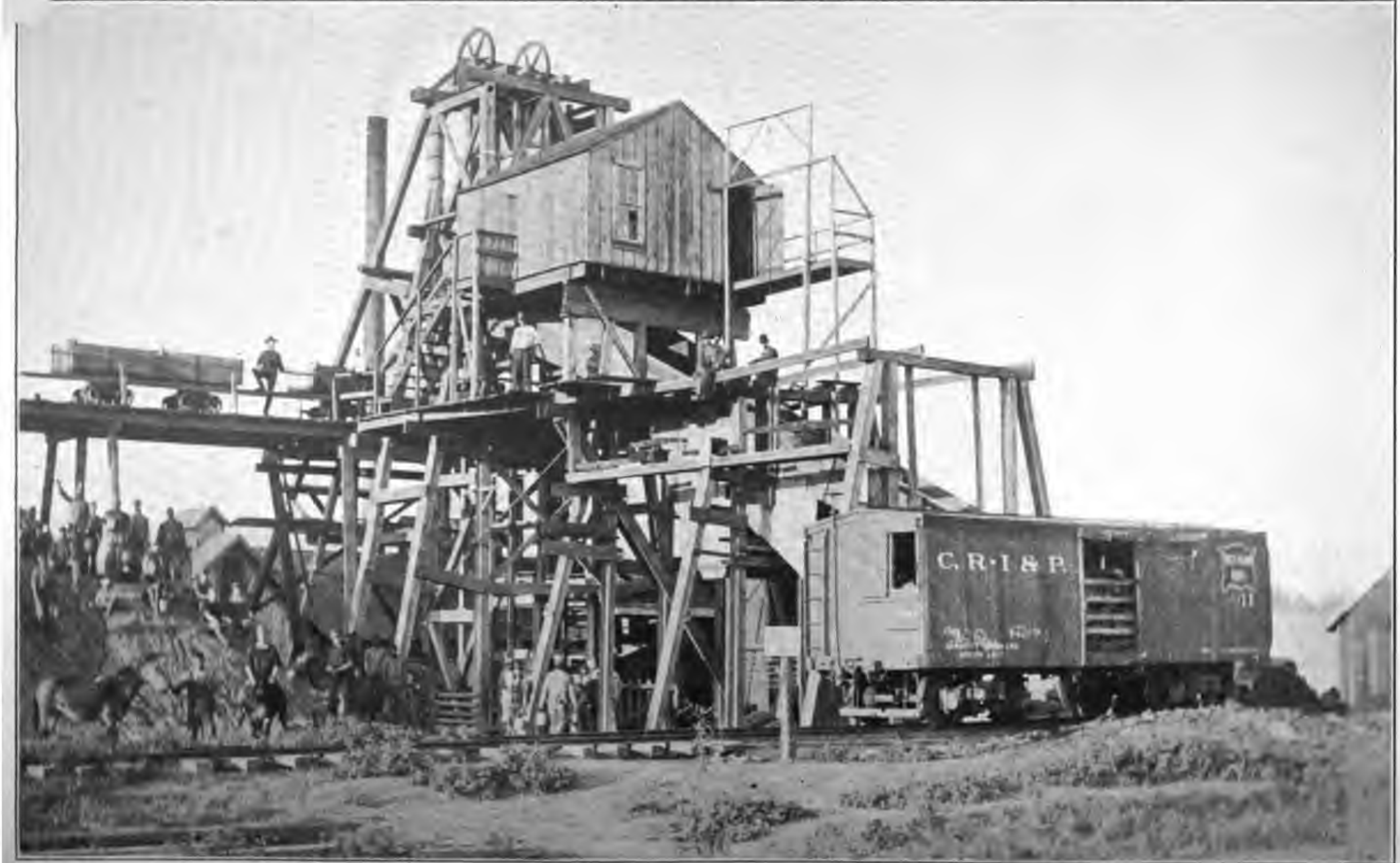
No. 1534. Smith-Lee Mine, Cisco, Eastland county. ✓

The analyses of these coals were made by O. H. Palm and S. H. Worrell and were published in Bulletin No. 3, University Mineral Survey, May, 1902. They were as follows:

TABLE II.

Composition of Texas Coals—Sampled at Mines by University Mineral Survey, 1901-1902.

Analysis No.	Proximate Analysis.									Ultimate Analysis.								Heat Value.		Specific Gravity—Dry.	Weight per Cubic Foot —Pounds—Dry.
	Natural condition.					Dry basis.				Natural condition.				Dry basis.				British thermal units.			
	Moisture.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Natural Condition.	Dry Basis.		
1518........	4.09	47.95	38.89	9.07	2.45	50.00	40.55	9.45	2.56	66.70	5.35	10.85	1.47	69.55	5.58	11.32	1.54	11,052	12,566	1.29	80.6
1519........	3.46	48.84	36.61	11.09	2.09	50.70	37.93	11.37	2.17	66.65	5.65	7.46	3.62	69.04	5.91	7.73	3.75	12,036	12,470	1.32	82.5
1520........	9.40	33.08	40.09	17.43	1.28	36.52	44.26	19.22	1.42	62.55	4.14	8.07	1.63	64.06	4.57	8.92	1.81	11,149	12,317	1.41	87.1
1521........	6.91	38.16	36.82	18.11	1.96	41.00	39.56	19.44	1.28	58.85	4.53	9.60	0.78	63.22	4.87	10.32	0.87	11,472	12,324	1.62	101.2
1522........	12.50	31.72	42.98	12.80	1.84	36.26	49.12	14.62	2.11	56.87	3.89	11.14	1.07	64.88	4.45	12.71	1.23	10,656	12,190	1.48	92.5
1523........	12.21	31.93	41.12	14.74	1.73	37.52	46.83	15.65	1.98	59.40	3.37	8.05	1.58	67.67	3.73	9.17	1.80	10,575	12,047	1.44	90.0
1524........	12.56	34.13	41.99	11.32	1.63	39.04	48.03	12.93	1.87	58.33	3.75	11.17	1.22	66.72	4.30	12.78	1.40	10,373	11,864	1.62	101.2
1525........	8.12	29.62	46.84	15.42	1.56	32.24	49.90	17.86	1.70	60.19	3.64	8.31	1.72	65.52	3.99	9.05	1.88	11,515	12,533	1.24	77.5
1526........	5.95	33.08	44.79	16.18	2.00	35.18	47.63	17.19	2.13	57.85	3.93	12.90	1.14	61.52	4.18	13.72	1.22	11,450	12,175	1.46	91.2
1527........	6.84	29.17	42.48	21.51	2.82	31.32	45.60	22.08	3.03	57,86	3.99	5.23	2.70	62.08	4.29	5.62	2.90	11,493	12,338	1.36	85.0
1528........	5.31	31.24	38.69	24.76	4.76	33.00	40.86	26.14	5.03	57.13	3.80	2.34	1.69	60.34	4.12	2.58	1.79	11,171	11,707	1.42	88.7
1529........	5.36	31.91	43.03	19.70	2.04	33.72	45.47	20.81	2.16	59.27	3.96	8.35	1.49	62.43	4.19	8.83	1.58	11,450	12,099	1.10	68.7
1530........	5.46	35.66	49.17	9.71	1.61	37.72	52.01	10.27	1.71	70.48	4.95	6.60	1.16	74.56	5.24	6.99	1.23	12,003	13,755	1.36	85.0
1531........	5.83	33.20	43.15	17.82	1.51	35.26	45.83	18.91	2.77	60 90	4.00	6.26	2.58	64.68	4.25	6.65	2.74	11,448	12,157	1.27	79.4
1532........	4.31	35.61	44.55	15.53	3.00	37.22	46.56	16.22	3.14	58.27	4.88	6.74	1.82	66.57	5.11	7.05	1.91	12,264	12,817	1.40	87.5
1533........	4.00	31.78	42.04	22.18	2.39	33.11	43.80	23.09	2.49	58.01	4.06	6.62	2.74	60.43	4.23	6.90	2.86	11,524	12,005	1.44	90.0
1534........	13.44	34.86	36.37	15.33	2.54	40.28	42.02	17.70	2.94	50.94	4.41	11.86	1.46	58.86	5.10	13.71	1.69	9,609	11,101	1.60	100.0
Average...	7.40	34.82	41.74	16.04	2.19	37.65	45.06	17.29	2.38	60.01	4.25	8.33	1.76	64.79	4.59	9.00	1.90	11,245	12,035	1.40	87.5



Bridgeport Coal Co.'s shaft No. 2, Bridgeport, Wise County.

The Cretaceous coals here represented are Nos. 1518, 1519, 1520, and 1521, the two former from Webb county, Laredo district, and the two latter from Maverick county, Eagle Pass district. The Webb county coals are higher in volatile combustible matter and sulphur, and lower in ash and moisture than the Maverick county coals, the fixed carbon being about the same. The Cretaceous coals from these counties show a considerable difference in the composition of the ash, as will appear further along. The Carboniferous coals, Nos. 1522 to 1534, inclusive, show a marked range in composition. On the average they contain more moisture, fixed carbon, ash and sulphur, with less volatile combustible matter than the Cretaceous coals.

From the composition of the ash of the Texas coals it may be concluded that while the coal was forming there were considerable variations in the character of the vegetation and in the character and amount of the sediments washed in. If we allow that the rate of accumulation of vegetable matter is 100 tons per acre per century and allow, also, for the differences in density and composition, it is likely that the rate of the formation of coal will not exceed one foot in 10,000 years. During such a period there would probably be many opportunities for climatic changes affecting the character of the vegetation, and for changes in the nature of the sediments mixed with the coal while it was forming.

In these coals, as mined, the following variations in composition were observed:

	From	To	Average.
Moisture	3.46	13.44	7.40
Volatile combustible matter	29.17	48.84	34.82
Fixed carbon	36.37	49.17	41.74
Ash	9.07	24.76	16.04
Sulphur	1.28	4.76	2.19
Carbon	50.94	70.48	60.01
Hydrogen	3.37	5.65	4.25
Oxygen	2.34	12.90	8.33
Nitrogen	0.78	3.62	1.76
British thermal units. per pound	9,609	12,264	11,245

On dry basis, these become:

	From	To	Average
Volatile combustible matter	31.32	50.70	37.65
Fixed carbon	37.93	52.01	45.06
Ash	9.45	26.14	17.29
Sulphur	1.28	5.03	2.38
Carbon	58.86	74.56	64.79
Hydrogen	3.73	5.94	4.59
Oxygen	2.58	13.72	9.00
Nitrogen	0.87	3.75	1.90
British thermal units per pound	11,101	13,755	12,035

Composition of the Ash of Texas Coals.

In Texas coals, as mined, the ash varied from 9.07 to 24.76 per cent., the average being 16.04 per cent.

In 1902, the University Mineral Survey made detailed analyses of the ash of Texas coals and it has not been thought necessary to repeat this work. The following table gives the results of these analyses, made by O. H. Palm and S. H. Worrell:

Composition of the Ash of Texas Coals.

Analysis No.	Silica	Alumina	Oxide of iron	Lime	Magnesia	Oxide of Manganese	Sulphuric acid	Per cent. of ash in coal as mined
1518	42.08	24.79	23.03	4.69	None	1.75	4.57	9.07
1519	44.48	35.62	14.74	2.56	Trace	....	3.52	11.09
1520	65.34	30.04	3.38	0.91	0.36	0.80	0.80	17.43
1521	62.72	21.56	9.84	0.64	0.70	....	Trace	18.11
1522	34.16	24.76	13.56	16.08	....	....	12.19	12.80
1523	34.32	14.62	22.94	14.85	1.42	1.16	10.97	14.74
1524	34.46	14.10	13.26	22.08	1.43	Trace	12.87	11.32
1525	50.50	24.46	15.40	4.21	Trace	Trace	2.84	15.42
1526	52.88	32.20	13.56	1.16	Trace	....	Trace	16.18
1527	47.20	17.88	28.02	1.35	1.47	....	Trace	21.51
1528	32.50	32.40	20.61	5.68	Trace	....	6.64	24.76
1529	52.06	41.12	4.00	1.08	1.50	....	1.67	19.70
1530	48.04	43.92	3.68	2.16	Trace	....	0.84	9.71
1531	48.20	26.20	22.02	0.81	1.34	....	0.96	17.82
1532	49.12	25.71	24.37	Trace	....	....	Trace	15.53
1533	51.34	13.10	28.02	1.56	2.25	....	2.32	22.18
1534	29.14	15.56	13.42	20.73	1.91	Trace	15.00	15.33
Average	45.97	25.94	16.11	5.97	0.73	0.22	4.42	16.04

The Cretaceous coals, from the Rio Grande field, are Nos. 1518, 1519, 1520, 1521, the first two being from Webb county, Laredo district, and the last two from Maverick county, Eagle Pass district. The ash of these coals shows a considerable difference in composition. The Webb county coals are low in silica and high in oxide of iron, with a medium content of alumina, lime and sulphuric acid. The Maverick county coals are high in silica and low in oxide of iron and sulphuric acid. As these coals are supposed to be of the same geological age, and to have been formed under relatively the same conditions, we may infer that the vegetation from which they were made was of a different character, and that the in-wash of sediments varied a good deal.

The coals of the Carboniferous formation also show considerable differences with respect to the composition of the ash, and this likewise would lead one to suppose that the character of the vegetation varied a good deal during the coal-forming period. In these coals the silica varies from 29.14 to 54.34 per cent; the alumina from 13.10 to 32.40 per cent; the oxide of iron from 3.68 to 28.02 per cent; the lime from a trace to 22.08 per cent; the magnesia from a trace to 2.25 per cent; and the sulphuric acid (combined, not free) from a trace to 15.00 per cent.

It is impossible to observe these analyses without reaching the conclusion that the character of the coal-forming vegetation changed a good deal during Carboniferous times, from plants which secreted a comparatively small amount of silica to those secreting a large amount. This observation also holds true with respect to the oxide of iron, alumina, lime and sulphuric acid, for the composition of the ash of coal is closely related to that of the plants from which the coal was made. Of course, the washing in of sediments which became mechanically mixed with the decaying vegetation has also to be considered, but, aside from this the ash of coal is largely the ash of the plants forming the coal. There are many interesting things found in the ash of coal, besides those already given, and in two Texas coals, both from Thurber, Erath county, copper was found in very small amounts. In a speculative way the occurrence of copper in the ash of these coals may be connected with the occurrence of copper in the Permian beds which lie to the west of the Carboniferous formation in Texas, and which are geologically above this formation.

For domestic purposes, where no great heat is required, more consideration is given to the quantity of ash in coal than to its fusibility. For boiler use, however, the fusibility (clinkering) of coal is a factor of great importance. Coal that clinkers badly, i. e., coal that has an easily fusibile ash, is almost sure to give more or less trouble. It clings to the grate-bars, interferes with the draft and causes, at times, serious losses. Such clinkering troubles generally attend the use of coal whose ash is high in oxide of iron. On the contrary, coals whose ash is composed chiefly of silica and alumina, or silica, alumina and lime, do not clinker so readily. As a rule, red ash coals clinker much more easily than white or gray ash coals.

The design and construction of the grate and fire-box and the method of firing have also a good deal to do with clinkering.

Specific Gravity and Weight per Cubic Foot.

The specific gravity of Texas coals, as mined, varies from 1.02, as in a coal from Erath county, to 1.51, as in a coal from Maverick county. The Cretaceous coals, from Maverick and Webb counties (Rio Grande Field) vary in specific gravity from 1.24 to 1.51, the average being 1.33. The variation in the Carboniferous coals is from 1.02 to 1.39, the average being 1.29.

On a dry basis the variation in the Cretaceous coals is from 1.29 to 1.62, the average being 1.41, and in the Carboniferous coals from 1.10 to 1.62, the average being 1.39.

On a dry basis the weight per cubic foot in the Cretaceous coals varies from 80.6 to 101.2 pounds, the average being 87.8 pounds. In the Carboniferous coals the variation is from 68.7 to 101.2 pounds, the average being 87.4 pounds.

The general average weight of all of the coals, is 81.10 pounds per cubic foot as mined, and 87.50 pounds on a dry basis.

A bushel of coal weighs from 76 to 80 pounds, according to legal enactment in the several States.

We have thus far considered the composition of Texas coals as represented by samples taken at the mines. These samples were secured in 1901-1902 and analyzed at that time. Beginning in the fall of 1910 and continuing into the spring of 1911, we solicited samples from the operating companies. The cans sent were provided with closely-fitting covers, but were not sealed. The moisture was determined at once upon receipt of the samples, so that there was very little, if any, loss of moisture from the samples. One or two of the larger samples came in closely nailed boxes.

By making analyses of these company samples and comparing the results with those obtained from our own samples, it was hoped that we would arrive at a fair statement of the composition of Texas coals. But few samples were taken at points of delivery and consumption, as we had not the means to do this.

Following is the description of the samples received:

No. 1. Belknap Coal Co., Newcastle, Young county.
No. 53. Belknap Coal Co., Newcastle, Young county.
No. 2. Bridgeport Coal Co., Bridgeport, Wise county.
No. 3. Cannel Coal Co., Laredo, Webb county.
No. 4. International Coal Mines Co., Eagle Pass, Maverick county.
No. 5. International Coal Mines Co., Special.
No. 6. Nos. 6, 31, 32, 33, 50, 51 and 52. Olmos Coal Co., Eagle Pass, Maverick county.
No. 31. Washed egg.
No. 32. Washed nut.
No. 33. Washed pea.
No. 50. Washed pea.
No. 51. Washed nut.
No. 52. Washed egg.
No. 42. Olmos washed nut. Sampled at McNeil, Texas.
No. 43. Olmos run-of-mines. Sampled at McNeil, Texas.
No. 8. Rio Grande Coal Co., Laredo, Webb county.
No. 37. Stewart Creek Coal Co., Jermyn, Jack county.
No. 10. Texas & Pacific Coal Co., Thurber, Erath county.
No. 11. Wise County Coal Co., Bridgeport, Wise county.

Nos. 42 and 43, Olmos washed nut and mine-run, were taken at the works of the Austin White Lime Co., McNeil, where producer gas was made for burning lime. Olmos mine-run is no longer marketed.

The analyses of these coals were as follows:

TABLE III.

Composition of Texas Coals—Samples Received from the Companies, 1910-1911. Analyses by S. H. Worrell

Analysis No.	As Received.										Dry Basis.								
	Proximate analysis.					Ultimate analysis.					Proximate analysis.				Ultimate analysis.				
	Moisture.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Heating Power B. t. u. per lb.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Heating Power B. t. u. per lb.
1	11.00	34.22	37.99	16.79	3.77	51.84	3.71	11.00	1.89	9,090	38.45	42.68	11.87	4.24	58.25	4.17	12.35	2.12	10,213
53	7.00	37.56	40.18	15.26	1.99	56.93	4.74	11.29	2.79	10,203	40.38	43.20	16.42	2.13	61.21	5.09	12.15	3.00	10,970
2	9.40	34.65	42.53	13.42	3.09	61.49	3.99	8.47	2.54	10,144	38.30	46.94	14.76	3.41	65.42	4.40	9.21	2.80	11,196
3	2.30	52.78	37.10	7.82	2.20	69.41	5.53	9.06	2.94	12,315	54.00	37.97	8.03	2.25	71.04	5.65	10.03	3.00	12,604
4	4.85	38.30	46.30	10.55	2.04	64.22	4.83	12.34	1.40	11,128	40.25	48.65	11.10	2.14	67.38	4.83	13.08	1.47	11,695
5	8.20	35.99	53.00	2.81	1.66	70.62	4.67	10.53	1.51	11,500	39.20	57.73	3.07	1.80	74.74	5.08	13.67	1.64	12,527
6	6.50	31.51	37.37	24.62	1.87	51.84	3.88	8.91	2.38	9,010	33.70	39.96	26.34	2.00	55.44	4.14	9.56	2.52	9,636
31	5.40	35.05	42.09	16.56	1.23	60.66	4.66	9.84	1.65	10,921	38.00	44.49	17.55	1.30	64.12	4.92	10.41	1.74	11,545
32	5.30	35.58	38.35	20.77	1.61	56.83	4.39	8.39	1.71	10,235	37.58	40.49	21.93	1.70	60.01	4.63	9.93	1.80	10,807
33	5.70	33.48	36.93	23.89	1.70	53.94	4.15	7.50	3.12	9,819	35.50	39.16	25.34	1.80	57.20	4.40	7.96	3.30	10,412
42	4.20	36.55	32.35	26.95	1.71	48.38	3.88	13.31	2.62	9,772	38.15	33.76	28.09	0.74	50.44	4.04	13.96	2.73	10,200
43	3.64	28.82	37.20	30.34	0.54	49.37	3.60	11.35	1.16	10,600	29.90	38.60	31.50	0.56	51.23	3.73	11.78	1.20	11,000
50	4.90	33.10	37.28	24.72	1.55	53.34	3.81	10.43	1.25	9,871	34.80	39.19	26.01	1.62	56.08	4.00	10.98	1.31	10,380
51	5.20	34.53	40.94	19.23	1.48	53.78	3.92	14.27	2.12	10,163	36.42	43.07	20.51	1.56	56.72	4.13	14.95	2.13	10,720
52	5.30	37.11	41.69	15.90	1.14	58.79	3.98	13.26	1.63	10,808	39.18	44.02	16.80	1.20	62.08	4.20	14.00	1.72	11,412
8	2.80	49.05	37.04	11.11	2.04	64.22	5.56	11.84	2.43	11,412	50.45	38.10	11.45	2.09	66.06	5.72	12.18	2.50	11,740
7	3.50	38.12	49.21	9.17	2.03	68.42	4.69	8.96	3.23	11,976	39.50	50.99	9.51	2.10	70.91	4.85	9.29	3.34	12,410
9	2.90	38.46	48.13	10.51	3.08	67.97	5.01	7.90	2.63	10,910	39.60	49.56	10.84	3.17	70.00	5.15	8.14	2.70	12,265
10	2.70	40.82	48.73	7.75	1.93	69.85	5.21	10.45	2.11	12,188	41.95	50.08	7.97	1.98	71.78	5.35	10.75	2.17	12,526
37	10.24	34.28	35.02	20.46	1.66	54.11	3.39	8.86	1.28	9,434	38.18	39.01	22.81	1.84	60.28	3.77	9.88	1.42	10,510
11	9.20	33.96	43.02	13.82	1.82	57.94	4.24	10.33	2.65	10,233	37.40	47.37	15.23	2.00	63.80	4.67	11.40	2.90	11,269
Average.	5.82	36.89	41.07	16.30	1.86	59.23	4.37	10.39	2.05	10,558	39.09	43.57	17.34	1.98	62.76	4.66	11.00	2.26	11,240

TABLE IV.

Proximate Analyses of Texas Coals—Alphabetically Arranged—Dry Basis.

Analysis No.		Volatile combustible matter	Fixed carbon	Ash	Sulphur	Heating power B. t. u.
1	Belknap Coal Co.— Newcastle, Young County......	38.45	42.68	11.87	4.24	10,213
53	Belknap Coal Co.— Newcastle, Young County......	40.38	43.20	16.42	2.13	10,970
2	Bridgeport Coal Co.— Bridgeport, Wise County.......	38.30	46.94	14.76	3.41	11,196
3	Cannel Coal Co.— Laredo, Webb County..........	54.00	37.97	8.03	2.25	12,604
4	International Coal Mines Co.— Eagle Pass, Maverick County...	40.25	48.65	11.10	2.14	11,695
5	International Coal Mines Co. (Spl.) International Coal Mines Co.—	39.20	57.73	3.07	1.80	12,527
6	Olmos Coal Co.— Eagle Pass, Maverick County.—	33.70	39.96	26.34	2.00	9,636
31	Olmos Coal Co.— Washed egg..................	38.00	44.49	17.55	1.30	11,545
32	Olmos Coal Co.— Washed nut..................	37.58	40.49	21.93	1.70	10,807
33	Olmos Coal Co.— Washed pea..................	35.50	39.16	25.34	1.80	10,412
50	Olmos Coal Co.— Washed pea..................	34.80	39.19	26.01	1.62	10,380
51	Olmos Coal Co.— Washed nut..................	36.42	43.07	20.51	1.56	10,720
52	Olmos Coal Co.— Washed egg..................	39.18	44.02	16.80	1.20	11,412
42	Olmos Coal Co.— Washed nut..................	38.15	33.76	28.09	0.74	10,200
43	Olmos Coal Co.— Mine run....................	29.90	38.60	31.50	0.56	11,000
8	Rio Grande Coal Co.— Laredo, Webb County..........	50.45	38.10	11.45	2.09	11,740
7	Santo Mining & Developing Co.— Weatherford, Parker County....	39.50	50.99	9.51	2.10	12,410
802	Santo Tomas Coal Co.— Laredo, Webb County..........	47.52	39.18	13.30	2.05	12,470
9	Strawn Coal Mining Co.— Strawn, Palo Pinto County....	39.60	49.56	10.84	3.17	12,265
10	Texas & Pacific Coal Co.— Thurber, Erath County.........	41.95	50.08	7.97	1.98	12,526
37	Stewart Creek Coal Co.— Jermyn, Jack County..........	38.18	39.01	22.81	1.84	10,510
11	Wise County Coal Co.— Bridgeport, Wise County.......	37.40	47.37	15.23	2.00	11,269
	Average..................	39.00	43.37	17.63	2.00	11,291

In this table the Carboniferous coals are Nos. 1, 2, 7, 9, 10, 11, 37 and 53. The Cretaceous coals are Nos. 3, 4, 5, 6, 8, 31, 32, 33, 42, 43, 50, 51 and 208.

On comparing these analyses with the analyses made on personal samples we find as follows, the first figures representing company samples and the latter figures personal samples, averages alone being given:

	Company samples, per cent.	Personal samples, per cent.
Moisture	5.82	7.40
Volatile combustible matter	36.89	34.82
Fixed carbon	41.07	41.74
Ash	16.30	16.04
Sulphur	1.86	2.19
Carbon	59.23	60.01
Hydrogen	4.37	4.25
Oxygen	10.39	8.33
Nitrogen	2.05	1.76
Heating power, B. t. u., per pound	10,558	11,245

On dry basis, these become:

	Company samples, per cent.	Personal samples, per cent.
Volatile combustible matter	39.00	37.65
Fixed carbon	43.37	45.06
Ash	17.63	17.29
Sulphur	2.00	2.38
Carbon	62.76	64.79
Hydrogen	4.66	4.59
Oxygen	11.00	9.00
Nitrogen	2.26	1.90
Heating power, B. t. u., per pound	11,291	12,035

There are no very considerable discrepancies between these analyses, and it may fully be concluded that they represent the composition of Texas coals as they are mined. It must be remembered that they do not pretend to represent the composition or heating value of the coals as they are used in actual practice. This is a matter to be adjusted between the buyer and the seller. If the consumer is willing to continue the use of a system by which he buys so much coal at such and such a price, without regard to composition and its heating power, he is, of course, free to do so. At the same time he must remember that he is not getting from his money its full service. He may be handling twice as much ash as may be necessary. He may be getting many heat units less than he is entitled to, but so long as he does not buy coal under specifications, but simply on a tonnage basis, he will continue to get a good deal less from a dollar than it has in it.

These remarks apply not only to Texas coals, which represent a small proportion of the coal used here, but to all classes of coal brought in from Alabama, West Virginia, Pennsylvania, Kentucky, Arkansas, Oklahoma, Colorado and New Mexico.

Other Analyses of Texas Coals.

Brewster County.

In the southern part of Brewster county, within 8 to 10 miles of the quicksilver area, there is a limited field of sub-bituminous coal. This coal has been used under steam boilers with satisfactory results. We give three analyses of the coal from the Rough Run district.

	Cub Spring, per cent.	**Kimble Pits, per cent.**	**Chisos Pen, per cent.**
Moisture	10.65	4.74	1.16
Volatile combustible matter	50.91	29.84	32.79
Fixed carbon	19.52	49.84	44.53
Ash	18.92	15.58	21.52
	100.00	100.00	100.00
Sulphur	0.86	1.26	3.39
Heating power, B. t. u. per pound	8,432	11,887	11,95

This coal field is 90 miles south of the Southern Pacific Railway, at Alpine or Marathon. The coal can be used only for local purposes, but it could be used in producers for making gas for the quicksilver furnaces instead of wood. There are outcrops of this coal within two miles of furnaces. The Rattlesnake beds, 20 miles south of the Rough Run district, are probably a continuation of the northern beds.

Burnet County.

In Bulletin No. 55, United States Geological Survey, 1889, page 87, there is given an analysis of coal from Burnet county, exact locality not given. The analysis was made by J. Edward Whitfield, and was as follows:

	Per cent.
Moisture	3.72
Volatile combustible matter	42.27
Fixed carbon	39.41
Ash	14.60
Sulphur and B. t. u. not given.	100.00

Coleman County.

In the Fourth Annual Report of the Texas Geological Survey, 1893, pages 433-435, there are given eight analyses of coal from the southern part of Coleman county, near the Colorado river, and from the Silver Moon Mine, northwest of Santa Anna. These analyses are as follows:

Analyses of Coal from Coleman County.

	Star & Crescent Co., near Rockwood. Average of 6 analyses	Silver Moon Mine N. E. of Santa Anna. Average of 2 analyses
Moisture	3.07	2.36
Volatile combustible matter	33.05	38.55
Fixed carbon	39.10	43.88
Ash	24.78	15.21
	100.00	100.00
Sulphur	3.10	5.91

One of the coals from the Star and Crescent property gave moisture, 4.71; volatile combustible matter, 39.26; fixed carbon, 46.24; ash, 9.79, and sulphur, 2.22. This is the best analysis given. The analyses from the Silver Moon property represent a fair average of that coal, vicinity of Jim Ned creek.

None of these coals is now worked, except, perhaps, for purely local purposes.

In the First Annual Report of the Texas Geological Survey, 1889, page 215, there are given five analyses of coal from different parts of the Waldrip beds, McCulloch county (Carboniferous), and in Coleman county. These are as follows in percentages:

Analyses of Coal from the Waldrip Beds, Coleman County.

LOCALITY	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur
Waldrip	8.25	38.27	47.27	6.20	3.25
*Waldrip	4.55	38.50	44.80	12.14	7.96
Bull Creek and Coleman County	4.05	40.40	46.75	8.80	2.87
Bull Creek	10.40	35.94	49.46	4.19	1.53
Silver Moon Mine	6.90	36.00	41.10	16.00	4.56

*Sample taken from the dump; not considered a fair sample.

In the Second Annual Report of the Texas Geological Survey, 1890, page 551, there are given six analyses of Texas coals, as follows in percentages:

LOCALITY	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur
Bridgeport, Wise County	2.00	31.47	56.32	8.15	2.06
Thurber Shaft, near Bowie, Montague County[1]	2.30	34.48	61.28	0.60	1.14
Gilfoil Shaft, Young County	1.10	35.50	43.00	15.60	4.60
Thurber Shaft No. 1, Erath County	0.85	31.23	56.98	9.30	1.64
Thurber Shaft No. 2, Erath County	0.90	30.96	60.01	6.85	1.28
Thurber Shaft No. 3, Erath County	0.90	33.51	53.46	10.65	1.48
Santo Tomas Coal, Webb County	2.59	51.05	39.01	7.35	1.50
From 25 miles N. W. of Santo Tomas, Webb County[2]	2.35	42.67	37.59	16.55	0.86

[1] No coal is now mined in Montague County.

[2] Brown Coal and Lignite, Dumble, 1892, p. 190.

The analyses of the coal from near Bowie, Montague county, is quite remarkable as showing only 0.60 per cent of ash.

In a note appended to these analyses it is stated that the coal from the Gilfoil shaft, Young county, was taken from the dump, and was not a fair sample.

Jack County.

An analysis of coal from Lost Valley, Jack county, has been given to us, with no name signed. This analysis was as follows:

	As received, per cent.	Dry, per cent.
Moisture	10.28	....
Volatile combustible matter	25.49	28.11
Fixed carbon	55.10	60.77
Ash	9.13	11.12
	100.00	100.00

Maverick County.

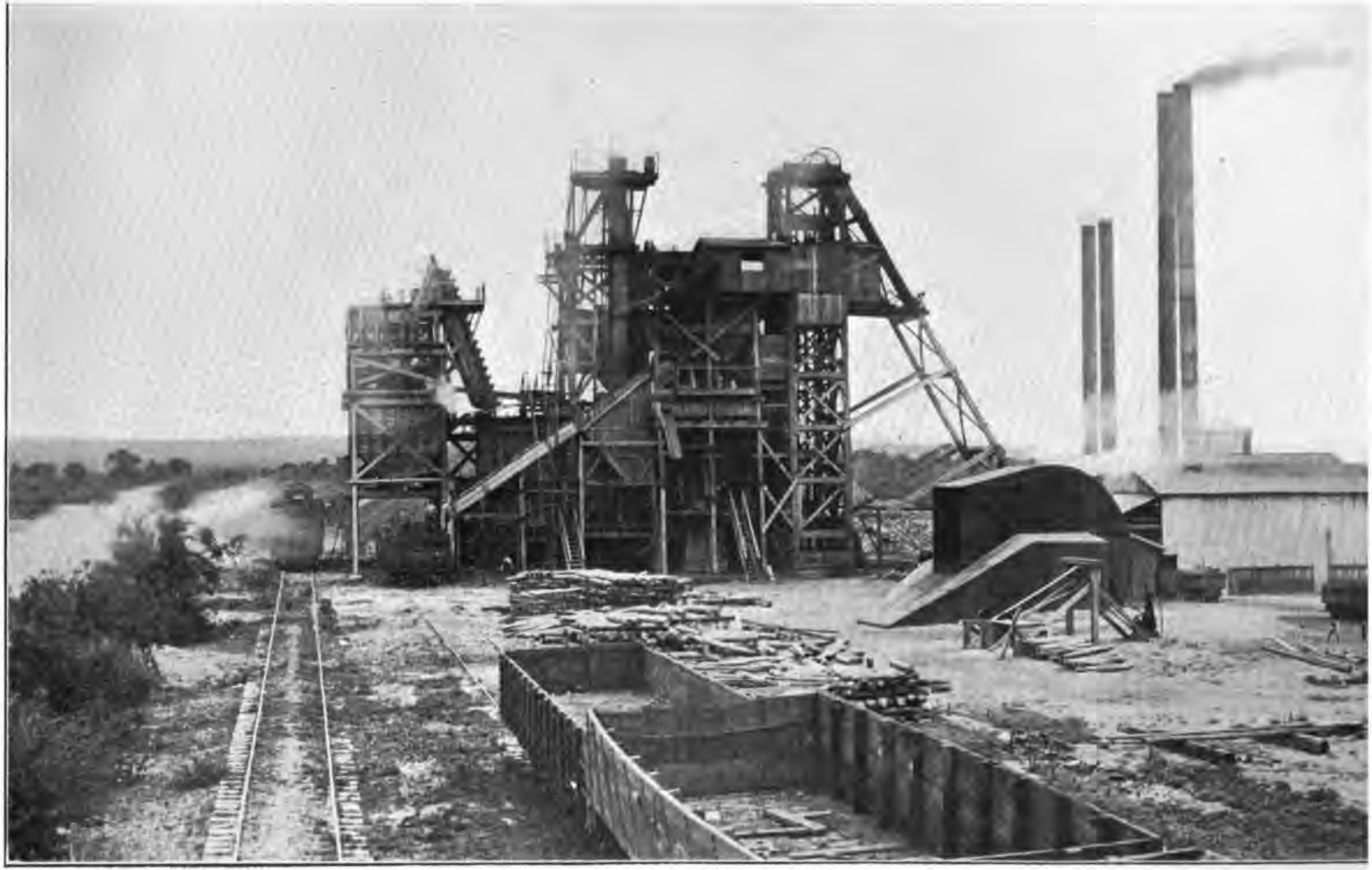
In Bulletin No. 164, United States Geological Survey, 1900, page 66, there is given an analysis of coal from near Eagle Pass, Maverick county, as follows:

	As received, per cent.	Dry, per cent.
Moisture	3.67	....
Volatile combustible matter	39.42	40.92
Fixed carbon	41.70	43.29
Ash	15.21	15.79
	100.00	100.00
Sulphur	0.81	....

The following analyses represent an average of the coal from the Dolch Mine, near Eagle Pass, Maverick county, and were made by the Bureau of Mines, Washington:

	Mch. 7, 1911, per cent.	Sept. 14, 1911, per cent.
Moisture	1.60	2.80
Volatile combustible matter	32.40	32.80
Fixed carbon	58.95	55.55
Ash	7.05	8.85
	100.00	100.00
Sulphur	1.70	0.80
B. t. u. per pound	14,020	13,165

We received from the Olmos Coal Company, Eagle Pass, in April, 1913, four samples of coal, one of lump and three of washed coal. These samples gave the following analyses:



Olmos Coal Co., Eagle Pass, Maverick County. Washer Plant.

Analyses of Coal from Olmos Coal Company, Eagle Pass, Maverick County.

	Washed pea.		Washed nut.		Washed egg.		Lump.	
	As rec'd, per cent.	Dry, per cent.	As rec'd, per cent.	Dry. per cent.	As rec'd, per cent.	Dry, per cent.	As rec'd, per cent.	Dry, per cent.
Moisture	11.11	....	7.98	....	8.68	....	8.83	....
Volatile combustible matter	28.53	32.10	30.00	32.60	30.94	33.88	32.68	35.84
Fixed carbon	42.26	47.54	40.06	43.54	42.94	47.02	44.89	49.24
Ash	18.10	20.36	21.96	23.86	17.44	19.10	13.60	14.92
Sulphur	1.06	1.19	0.94	1.02	0.90	1.02	0.90	0.99
British thermal units	9,698	10,910	9,681	10,520	10,361	11,455	10,941	12,001

Mr. C. S. Plant, Superintendent, Fuel Service, Sunset-Central lines, has kindly furnished us with the following analyses of coal from the Olmos Coal Company, Eagle Pass:

	Choice lump, per cent.	Ordinary lump and slack, per cent.	Washed egg, per cent.
Moisture	7.48	6.43	6.43
Volatile combustible matter	32.18	32.43	29.33
Fixed carbon	45.67	42.88	40.73
Ash	14.67	18.26	23.51
	100.00	100.00	100.00
B. t. u. per pound	11,530	11,240	10,146

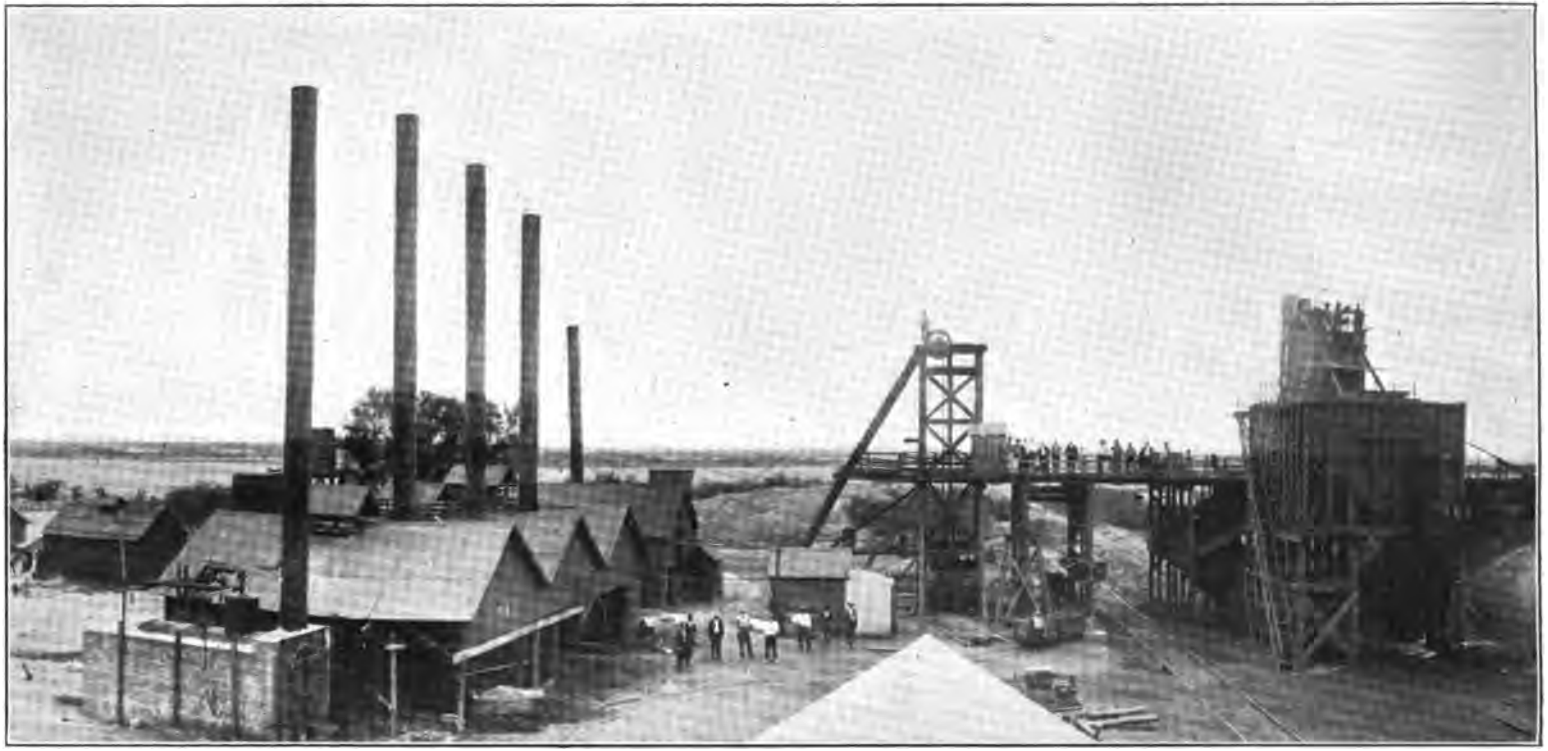
During the months of September and October, 1911, the International Coal Mines Company, Eagle Pass, Maverick county, sold 800 tons of coal to the Federal Government for use at Fort Sam Houston, San Antonio. The analyses were made by the Bureau of Mines, Washington, and were as follows:

	400 tons, Sept., 1911.		400 tons, Oct., 1911.	
	As rec'd, per cent.	Dry, per cent.	As rec'd, per cent.	Dry, per cent.
Moisture	2.80	....	1.50	....
Volatile combustible matter	32.80	33.74	33.40	33.91
Fixed carbon	55.55	57.15	58.95	59.85
Ash	8.85	9.11	6.15	6.24
	100.00	100.00	100.00	100.00
Sulphur	0.80	0.82	1.70	1.73
British thermal units per pound	13,163	13,544	14,020	14,213

Palo Pinto County.

We have received from the Strawn Coal Mining Company, Strawn, Palo Pinto county, an analysis of coal made for them by The Detroit Testing Laboratory, Detroit, Michigan, December 14, 1912. It was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	1.06	....
Volatile combustible matter	39.28	39.70
Fixed carbon	50.12	50.65
Ash	9.54	9.65
	100.00	100.00
Sulphur	2.88	2.91
British thermal units per pound	13,421	13,563



International Coal Mines Co., Eagle Pass, Maverick County.

Since December 10, 1912, we have examined five samples of coal from Strawn, Palo Pinto county, for Mr. J. R. Elliott, State Purchasing Agent. This coal was sampled from the bins and the boiler room of the State Epileptic Colony, Abilene, November 27, 1912; January 4 and 15, February 11 and March 20, 1913.

The average of the analyses was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	2.08	....
Volatile combustible matter	33.22	33.89
Fixed carbon	45.08	46.02
Ash	19.62	20.09
	100.00	100.00
Sulphur	3.96	4.05
British thermal units per pound	11,258	11,506

Presidio County.

This coal is in the San Carlos district, from 20 to 25 miles south of Chispa, a station on the Southern Pacific Railway, 145 miles southeast of El Paso.

Without, at this time, expressing any opinion concerning the value of that field from a commercial standpoint, except that it appears to be worth further investigation, we give two analyses of the coal which are quoted in the Mineral Resources of the United States, United States Geological Survey, 1893, page 385. The analyses were sent to that survey by Mr. R. E. Russell, General Manager of the San Carlos Coal Company, a Pittsburg organization. There were said to be two benches in the seam, separated by from 6 to 18 inches of slate. The lower bench was said to average from 30 to 40 inches and was softer than the upper bench, which was 32 inches, widening out, in places, to 6 feet or more.

Two analyses were given, but nothing is said as to which one represents the lower and which the upper bench.

Analyses of Coal from the San Carlos Field, Presidio County.

	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur
No. 1	1.00	39.05	49.05	10.00	Trace
No. 2	0.94	34.48	58.96	5.62	0.64

Mr. Russell said that coking tests of this coal had been made at Connellsville, Pennsylvania, and that 48-hour bee-hive coke gave carbon 93.7 per cent and ash 6.30 per cent.

A railroad test, made on coal that had been on the dump for five or six months, and that was practically crop coal, showed a haulage of 52.21 miles per ton of coal, passenger train with five or six coaches.

In Bulletin No. 164, United States Geological Survey, 1900, page 87, there are given five analyses of the San Carlos coal and one of coke, by Dr. Peter Fireman. These analyses were as follows:

Analyses of San Carlos Coal, Presidio County.

No. 4 MINE	Upper part of seam	Above binder	Below binder	Above clay, lower seam	Coal shaft
Moisture	1.09	1.17	1.19	1.68	0.97
Volatile combustible matter	36.61	39.93	39.73	60.37	40.95
Fixed carbon	35.29	35.39	40.30	24.89	43.77
Ash	24.01	23.51	18.78	13.06	14.31
	100.00	100.00	100.00	100.00	100.00

Sulphur and B. t. u. not given.

The analysis of the coke was:

	Per cent.
Moisture	1.24
Volatile combustible matter	4.96
Fixed carbon	66.93
Ash	26.87
	100.00

The coke was described as coherent, hard and lustrous.

During the summer of 1913, Dr. J. A. Udden, geologist for this Bureau, visited the field and brought back samples of the coal from two localities. The analyses are as follows:

Analyses of Coal from the San Carlos Coal Field, Presidio County, Texas. Samples collected by J. A. Udden, in July, 1913.

	Upper vein, 300 yards S. E. of old Ingle tunnel		Upper vein, near S. W. corner Sec. 67	
	As rec'd	Dry	As rec'd.	Dry
Moisture	4.60	....	4.90	....
Volatile combustible matter	39.20	41.13	32.80	34.49
Fixed carbon	50.10	52.47	43.04	45.26
Ash	6.10	6.40	19.26	20.25
	100.00	100.00	100.00	100.00
Sulphur	0.62	0.64	0.85	0.88
British thermal units per pound	12,157	12,757	9,663	10,161

The San Carlos Field would appear to merit a more careful examination than it has yet had, especially in view of the possibility of developing a good coking coal.

Stephens County.

The undeveloped coal in Stephens county, in the vicinity of Crystal Falls and up the Brazos river from this place; west and southwest of Breckenridge, etc., has not been sufficiently opened for one to express a positive opinion concerning it.

On Coal Branch, a few miles west of Crystal Falls, Stephens county, there is an outcrop of coal with two benches, each 12 inches thick, which was sampled by Wm. B. Phillips, December 13, 1906. The analysis was as follows:

Analysis of Coal from Coal Branch, Stephens County, Upper Bench.

	Per cent.
Moisture	6.90
Volatile combustible matter	38.07
Fixed carbon	37.03
Ash	18.00
	100.00
Sulphur	6.49

This coal contained an excessive amount of sulphur and experiments were made to see what proportion of it could be eliminated. A large sample was put through a ⅜-inch screen and thoroughly mixed. A sample was treated in zinc chloride solutions of specific gravity 1.30, 1.35 and 1.40. The coal that floated in 1.30 was 29.50 per cent of the total, and contained 11.34 per cent of ash, with 4.10 per cent of sulphur.

The coal that sank in the solution of 1.30 specific gravity, but floated in 1.35, was 29.50 per cent of the total, and contained 19.24 per cent of ash, with 5.36 per cent of sulphur. The coal that sank in 1.35, but floated in 1.40, was 4.50 per cent of the total, and contained 18.80 per cent of ash, with 6.29 per cent of sulphur.

The coal that sank in 1.40 was 36.50 per cent of the total and contained 35.60 per cent of ash, with 8.54 per cent of sulphur. It is not likely that this coal could be improved by washing to such an extent as to warrant the expense to be incurred. The best of it contains over 4 per cent of sulphur.

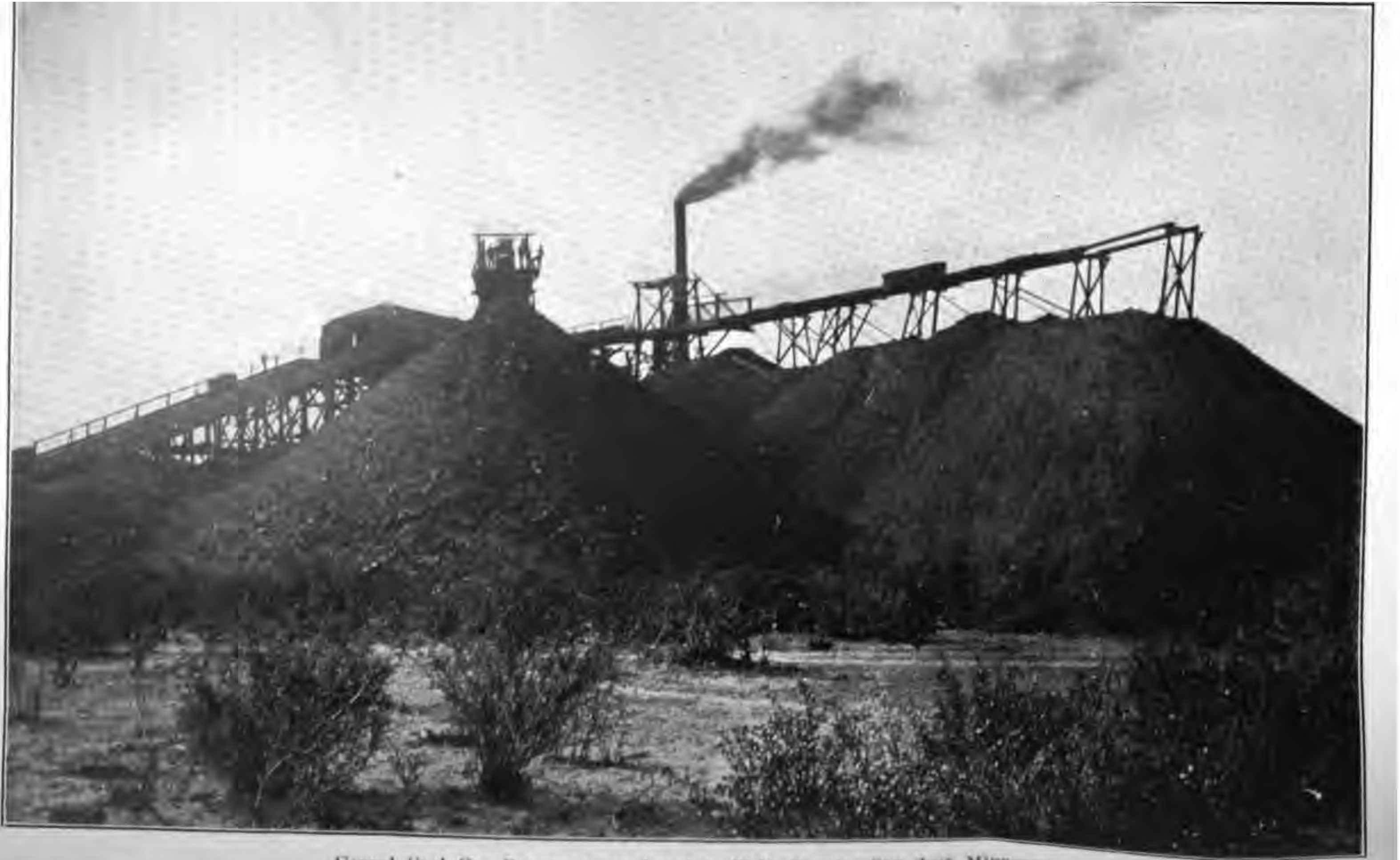
The bottom bench of this coal, separated from the upper bench by from 3 to 6 inches of bone and slate, shows a much better material.

Analysis of Bottom Bench of Coal, Coal Branch, Stephens County.

	Per cent.
Moisture	3.15
Volatile combustible matter	41.95
Fixed carbon	43.60
Ash	11.30
	100.00
Sulphur	3.75

The composition of the entire seam of 24 inches at this place would be:

	Per cent.
Moisture	5.02
Volatile combustible matter	40.01
Fixed carbon	40.46
Ash	14.51
	100.00
Sulphur	5.12



Cannel Coal Co., Darwin (near Laredo), Webb County, San José Mine.

There has been, of late, an increase of interest in the Stephens county coals, and some work is now being done there, but no coal has been shipped, as there are no railroad facilities.

Webb County.

We have received from the Cannel Coal Company, Laredo, Webb county, a copy of an analysis of their coal made by the Technologic Branch of the United States Geological Survey, Pittsburg, Pennsylvania, February 21, 1910. The sample represented a lot of 1,000 pounds taken at the mines by an agent of the Survey and was not freed of the impurities which are ordinarily removed when the coal is shipped on regular orders. The analysis is as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	3.97	....
Volatile combustible matter	43.63	45.43
Fixed carbon	36.15	37.65
Ash	16.25	16.92
	100.00	100.00
Sulphur	4.18	4.35
British thermal units per pound	11,588	12,067

An analysis of coal from the Laredo district, Webb county, has been given to us by Mr. Otto Stolley, Austin. It was made by Dr. J. R. Bailey, University of Texas, as follows:

	Llave coal.	
	As rec'd, per cent.	Dry, per cent.
Moisture	3.00	....
Volatile combustible matter	48.87	50.34
Fixed carbon	39.52	40.71
Ash	8.61	8.95
	100.00	100.00
Sulphur	3.52	3.63
British thermal units per pound	13,107	13,509

In Bulletin No. 164, United States Geological Survey, 1900, page 64, there are given two analyses, by Dr. Peter Fireman, of samples of coal from the Rio Grande Coal & Irrigation Company, near Laredo, Webb county. They are as follows:

	Upper bench.		Lower bench.	
	As rec'd, per cent.	Dry, per cent.	As rec'd, per cent.	Dry, per cent.
Moisture	2.26	....	2.63	....
Volatile combustible matter	48.64	49.77	45.67	46.91
Fixed carbon	36.15	36.99	39.96	41.04
Ash	12.95	13.24	11.74	12.05
	100.00	100.00	100.00	100.00
Sulphur, not given.				
British thermal units, not given.				

A sample of 25 pounds of coal received from the Santo Tomas Coal Company, Laredo, Webb county, June 17, 1912, gave the following analysis:

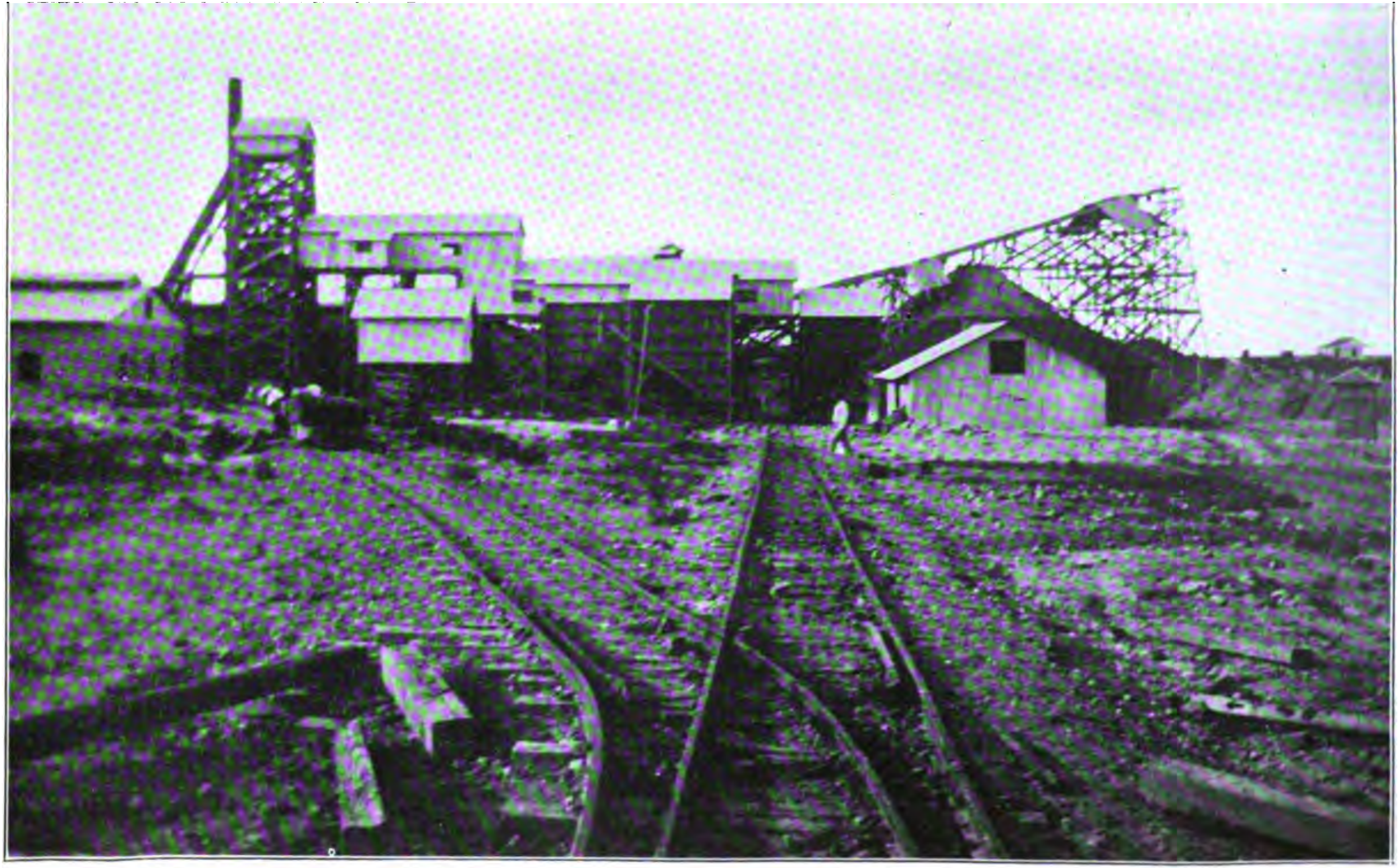
	As rec'd, per cent.	Dry, per cent.
Moisture	4.00	....
Volatile combustible matter	45.50	47.32
Fixed carbon	37.67	39.18
Ash	12.83	13.30
	100.00	100.00
Sulphur	1.97	2.05
British thermal units per pound	12,000	12,470

On October 12, 1912, we examined two samples of Santo Tomas Coal, Laredo, Webb county, for the University of Texas Powerhouse. The analyses were as follows:

	Special.		Carloads.	
	As rec'd, per cent.	Dry, per cent.	As rec'd, per cent.	Dry, per cent.
Moisture	2.60	....	2.50	....
Volatile combustible matter	46.49	47.70	45.27	46.40
Fixed carbon	38.98	40.00	29.27	30.00
Ash	11.93	12.30	22.96	23.60
	100.00	100.00	100.00	100.00
Sulphur	2.34	2.40	2.44	2.50
British thermal units per pound	12,339	12,660	10,917	11,190

Another analysis of Santo Tomas Coal is given in Table IV under No. 802.

From the best information to hand, derived from our own analyses and such as we have been able to procure, we think that the following statements of the average composition of Texas coals and the range of composition are reasonably correct.



Santo Tomas Coal Co., Minera (near Laredo), Webb County.

Average Composition of Texas Sub-bituminous Coals.

	As mined, per cent.	Dry, per cent.
Moisture	6.61	....
Volatile combustible matter	35.60	38.12
Fixed carbon	41.40	44.33
Ash	16.39	17.55
	100.00	100.00
Sulphur	2.12	2.28
British thermal units per pound	10,901	11,672
Carbon	59.62	63.84
Hydrogen	4.31	4.61
Oxygen	9.36	10.02
Nitrogen	1.90	2.03

These figures do not correspond exactly with the averages given on pages 15 and 21, but the discrepancies are due to taking a larger number of analyses than appear on those pages.

Taking the same number of analyses as are represented in the preceding statement, more than 60 in all, we find that the range of composition of these coals is as follows [natural condition]:

	From, per cent.	To, per cent.
Moisture	2.30	13.44
Volatile combustible matter	28.82	49.05
Fixed carbon	32.35	53.00
Ash	2.81	30.34
Sulphur	0.54	4.76
British thermal units per pound	9,010	12,315
Carbon	48.33	70.62
Hydrogen	3.37	5.65
Oxygen	2.34	14.27
Nitrogen	0.78	3.62

CHAPTER III.

COMPOSITION OF COALS BROUGHT INTO TEXAS.

We have attempted to secure analyses of coals brought into Texas from other States, but we have not been as successful as we could wish. We had not the means for sending a man to various cities and towns to secure samples in person, so that we have been compelled to accept samples that were sent in by coal companies or their agents. We have no means of ascertaining whether or not these samples correctly represent the coals as received and used and we distinctly disclaim all responsibility in the matter, except as to the analyses. The services of this Bureau have been and are still at the disposal of citizens of this State who wish to know the quality of the fuels they are using and we hope that the publication of this bulletin will be a means for calling attention to this important matter. It is likely that the value of the coals brought into this State, for railroad, industrial and domestic purposes, is not less than $10,000,000 annually.

Alabama Coals.

We have received a sample of coal marked "Alabama Lump." It was dry when received and had the following composition:

	Per cent.
Volatile combustible matter	38.50
Fixed carbon	56.00
Ash	5.50
	100.00
Sulphur	1.70
British thermal units, per pound	14,200

We have received from Jung & Sons Co., New Orleans, La., three samples of Alabama coal, which is marketed in Texas. The composition of these samples was as follows, in percentage:

	1. Per cent.	2. Per cent.	3. Per cent.
Moisture, as received	1.40	1.70	1.60
On Dry Basis—			
Volatile combustible matter	35.92	38.07	31.89
Fixed carbon	57.85	54.77	66.08
Ash	6.23	7.16	2.03
	100.00	100.00	100.00
Sulphur	0.85	1.71	1.08
British thermal units, per pound	13,989	13,944	15,126

1. Alecto Red Ash, Cahaba Field, Bibb county, Alabama.
2. Oak Hill Mine, White Ash Coal, Walker county, Alabama.
3. Bear's Creek, No. 3 Lump, Etowah county, Alabama.

We received from the Consumers Fuel and Ice Company, Austin, a sample of Alabama blacksmith coal, from Yolande. The composition of this sample was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	4.00	....
Volatile combustible matter	24.29	25.30
Fixed carbon	63.96	66.63
Ash	7.75	8.07
	100.00	100.00
Sulphur	0.86	0.90
British thermal units, per pound	13,499	14,061

The following analyses have been kindly furnished by Dr. Eugene A Smith, Director of the Geological Survey of Alabama, the analyses having been made by Mr. R. S. Hodges in the laboratory of that survey:

Analyses.	Moisture, per cent.	Volatile combustible matter, per cent.	Fixed Carbon, per cent.	Ash, per cent.	Sulphur, per cent.	B. t. u., per pound calculated.
1	1.62	35.53	52.13	10.72	2.23	13,077
2	1.60	35.35	49.45	15.60	2.99	12,718
3	1.37	29.57	58.78	10.28	1.08	13,651
4	1.89	28.32	61.52	8.27	1.08	13,802
5	1.00	31.02	59.46	8.52	1.26	12,999
6	0.97	32.00	58.38	8.65	1.37	Not det'd
7	0.73	28.58	65.05	5.64	1.38	Not det'd
8	0.80	29.80	64.46	4.94	1.32	14,783
9	1.83	35.00	56.65	6.52	0.65	Not det'd
10	1.02	26.13	63.42	9.43	0.99	*13,973
11	1.74	34.61	58.38	5.27	0.61	13,890
12	0.84	29.26	63.69	6.21	1.55	*14,495
13	1.39	32.66	52.47	13.48	0.53	Not det'd
14	1.54	32.48	54.83	11.15	0.59	*13,297
15	0.78	26.17	56.92	16.13	0.75	12,821
16	0.91	27.50	54.77	16.82	0.98	Not det'd
17	2.31	33.79	53.23	10.67	1.40	Not det'd
18	2.49	32.78	52.46	12.27	1.46	*12,515
19	1.11	37.74	56.85	4.30	0.44	14,688
20	0.98	36.75	57.04	5.23	0.51	14,365
21	1.39	36.48	55.24	6.89	0.36	13,946
22	1.35	36.57	54.08	8.00	0.39	13,623

*Determined by Bureau of Mines, Washington.

1. Deer Creek Coal Co., Tidewater.
2. Same.
3. Central Iron and Coal Co., Kellerman.
4. Same.
5. Alabama Consolidated Coal and Iron Co., Searles.
6. Tennessee Coal, Iron and Railway Co., No. 5 Pratt.
7. Tennessee Coal, Iron and Railway Co., No. 3 Pratt.
8. Tennessee Coal, Iron and Railway Co., No. 5 Pratt.
9. Tennessee Coal, Iron and Railway Co., No. 5 Blocton.
10. Tennessee Coal, Iron and Railway Co., No. 4 Johns.
11. Tennessee Coal, Iron and Railway Co., No. 7 Blocton.
12. Tennessee Coal, Iron and Railway Co., No. 3 Pratt.
13. Galloway Coal Co., Garnsey.
14. Same.
15. Alabama Consolidated Coal and Iron Co., Mary Lee.
16. Same.
17. Galloway Coal Co., No. 6 Carbon Hill.
18. Same.
19. Wadsworth Red Ash Coal Co., Falliston.
20. Same.
21. Conners Wyman Steel Co., Falliston.
22. Same.

The analyses sent to us by Dr. Smith included also the ultimate composition of these coals, but it does not appear necessary to give these determinations here, as our purpose is merely to show what is the proximate composition of well known Alabama coals.

Arkansas Coals.

We have received from the Dow Coal Co., McAlester, Oklahoma, a sample of coal marked "Hartford, Arkansas, semi-anthracite." The composition of this sample was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	1.20	....
Volatile combustible matter	16.74	16,94
Fixed carbon	77.32	78.26
Ash	4.74	4.80
	100.00	100.00
Sulphur	0.88	0.89
British terminal units, per pound	14,474	14,650

A sample of Arkansas semi-anthracite sold for domestic use in Austin at $10 a ton had the following composition:

	As rec'd, per cent.	Dry, per cent.
Moisture	1.14	....
Volatile combustible matter	11.54	11.67
Fixed carbon	73.22	74.06
Ash	14.10	14.27
	100.00	100.00
Sulphur	2.16	2.19
British thermal units, per pound	12,624	12,770

A sample of Arkansas semi-anthracite tåken in Austin, August 20, 1913, showed the following composition:

	As rec'd, per cent.	Dry, per cent.
Moisture	1.26	....
Volatile combustible matter	18.54	18.78
Fixed carbon	63.20	64.10
Ash	17.00	17.21
	100.00	100.00
Sulphur	1.28	1.30
British thermal units, per pound	12,390	12,548

Note.—As 50 per cent of this coal passed a ⅛-inch screen, it might be classed as slack.

We have received from the McAlester Fuel Co., McAlester, Oklahoma, a sample of Arkansas semi-anthracite marked "Bernice Slack." The composition of this sample was as follows:

	As rec'd, per cent.
Moisture	1.30
Volatile combustible matter	13.60
Fixed carbon	70.49
Ash	14.61
	100.00
Sulphur	2.25
British thermal units per pound	12,619

Colorado Coals.

Two samples of Colorado coal from Trinidad were obtained from the Consumers Fuel and Ice Co., Austin. The composition of these samples was as follows:

	I. As rec'd, per cent.	II. As rec'd, per cent.
Moisture	3.80	3.80
Volatile combustible matter	37.48	34.43
Fixed carbon	52.78	49.83
Ash	5.94	11.94
	100.00	100.00
Sulphur	0.88	0.84
British thermal units, per pound	13,271	11,995

The Colorado coals as used by the railroads in Texas carry about 3 per cent of moisture, from 30 to 35 per cent volatile combustible matter, from 50 to 55 per cent of fixed carbon, and from 8 to 12 per cent of ash.

Illinois Coals.

A little Illinois coal comes into Texas and we have received from Jung & Sons Co., New Orleans, a sample of Blue Ridge coal, Saline county, which had the following composition:

	As rec'd, per cent.	Dry, per cent.
Moisture	2.60	....
Volatile combustible matter	34.88	35.81
Fixed carbon	55.42	56.90
Ash	7.10	7.29
	100.00	100.00
Sulphur	2.23	2.29
British thermal units, per pound	13,150	13,501

Kentucky Coals.

Some Kentucky coal is marketed in Texas, but we are unable to give any analyses.

New Mexico Coals.

New Mexico coals are sold in El Paso and other cities and towns of west and northwest Texas. We give three analyses of these coals from samples taken in El Paso in September, 1913. These are as follows, as received:

	1. Per cent.	2. Per cent.	3. Per cent.
Moisture	4.35	1.50	1.12
Volatile combustible matter	3.15	36.96	35.48
Fixed carbon	79.70	46.54	50.20
Ash	12.80	15.00	13.20
	100.00	100.00	100.00
Sulphur	0.82	0.68	0.68
British thermal units, per pound	12,546	12,468	12,546

1. Anthracite from Cerrillos Coal Co., Albuquerque. Mines at Madrid. Sells in El Paso for $6.50 a ton.

2. Bituminous coal from Raton, Swastika Fuel Co., Raton. Sells in El Paso at $3.50 a ton, wholesale.

3. Dawson coal, sells in El Paso at $3.50 a ton, wholesale.

We have received from S. C. Awbrey & Co., El Paso, under date of September 18, a letter in which they state that the fixed carbon in Cerrillos coal is about 85 per cent, and the ash about 6 per cent. They have kindly sent us an analysis of a sample representing a carload which was shipped to Mexico City. This analysis is as follows:

	Per cent.
Moisture	2.92
Volatile combustible matter	4.35
Fixed carbon	85.09
Ash	6 84
Sulphur	0.79

They also inform us that the bituminous coal from the Raton district carries moisture from 0.85 to 1.70 per cent; volatile combustible matter from 36 to 41 per cent; fixed carbon from 51 to 53 per cent; and ash from 6 to 10 per cent.

Oklahoma Coals.

A great deal of coal from Oklahoma is brought into Texas, for railroad, industrial, and domestic purposes; but no statistics on the subject are now available. We have received from a number of operating companies samples of the coal shipped to Texas, and we herewith present the analyses which have been made on the same, as received:

Analysis.	Moisture, per cent.	Volatile combustible matter, per cent.	Fixed carbon, per cent.	Ash, per cent.	Sulphur, per cent.	B. t. u., per pound.
1	3.60	32.58	59.77	4.05	0.80	13,296
2	1.80	37.20	54.64	6.36	1.94	14,495
3	2.00	35.44	56.68	5.88	1.68	13,746
4	3.80	29.96	61.14	5.10	1.06	13,794
5	2.60	36.72	56.30	4.38	0.67	13,586
6	0.24	38.90	52.44	8.32	2.81	13,403
7	0.10	37.20	59.00	3.70	1.37	13,871
8	4.66	31.64	59.40	4.30	0.85	13,404
9	5.20	32.80	59.16	2.84	1.34	12,976
10	2.90	37.90	48.50	10.70	3.23	12,702
11	2.80	37.34	49.26	10.60	4.12	12,312
12	1.20	40.00	51.60	7.20	2.75	13,092
13	1.26	33.59	59.03	6.12	1.10	13,927
14	6.40	32.10	59.29	2.21	1.29	12,983
15	4.80	34.88	55.37	4.95	3.79	12,567
16	2.60	32.34	60.58	4.48	0.83	13,586
17	6.00	31.62	58.90	3.48	1.17	13,039
18	3.00	33.85	59.46	3.69	0.56	13,833
19	4.60	34.03	54.68	6.69	1.29	12,963
20	3.80	33.47	57.05	5.68	1.67	12,957
21	3.60	34.03	55.04	7.33	1.99	12,846
22	4.80	38.37	49.79	7.04	3.55	12,538
23	5.20	34.41	52.71	7.68	3.00	11,968
24	4.80	31.51	45.89	18.80	2.73	10,831
25	3.20	36.69	52.37	7.74	3.43	12,603
26	3.20	31.17	62.24	3.39	0.61	13,805
27	3.70	30.76	50.91	14.63	2.22	11,027
28	3.60	27.41	46.72	22.27	2.60	10,448
29	3.26	42.12	47.55	7.07	3.20	Not det'd
Average	3.40	35.17	54.98	7.09	1.98	12,503

1. From the receivers of the Bolen-Darnall Coal Co., McAlester; May 30, 1913.
2. Degnan-McConnell mines, Wilburton; July 18, 1913.
3. Dow Coal Co., Adamson; May 30, 1913.
4. Dow Coal Co., Savannah; June 16, 1913.
5. Dow Coal Co., Pocahontas; May 30, 1913.
6. Hailey-Ola Coal Co., Haileyville; July 19, 1913; No. 1 mine.
7. Hailey-Ola Coal Co., Haileyville; July 19, 1913; No. 2 mine.
8. Hailey-Ola Coal Co., Haileyville; July 19, 1913; No. 6 mine.
9. Henryetta Coal and Mining Co., Henryetta; June 28, 1913.
10. McAlester-Edwards Co., Pittsburg; July 18, 1913; mine-run from No. 1 mine.
11. McAlester-Edwards Co., Pittsburg; July 18, 1913; mine-run from No. 2 mine.
12. McAlester-Edwards Co., Pittsburg; July 18, 1913; washed nut.
13. McAlester Fuel Co., McAlester; August 15, 1913; Buck No. 6.

14. McAlester Fuel Co., McAlester; June 28, 1913; Pleasant Valley Coal Co. Coalton, No. 1 mine.

15. McAlester Fuel Co., McAlester; June 28, 1913; Pleasant Valley Coal Co. Coalton, No. 2 mine.

16. McAlester Fuel Co., McAlester; June 26, 1913; Great Western Coal and Coke Co., Wilburton, Mine No. 3.

17. Oklahoma Coal Co., Dewar, May 30, 1913.

18. Osage Coal & Mining Co., McAlester; June 25, 1913; No. 5 mine, McAlester vein.

19. Southern Fuel Co., McAlester, June 21; Brewer-McAlester domestic lump.

20. Southern Fuel Co., McAlester, June 21; Brewer-McAlester chestnut.

21. Southern Fuel Co., McAlester, June 21; Brewer-McAlester slack.

22. Southern Fuel Co,. McAlester, June 21; Caney Creek domestic lump, Coalgate.

23. Southern Fuel Co., McAlester, June 21; Caney Creek chestnut.

24. Southern Fuel Co., McAlester, June 21; Caney Creek slack.

25. Southern Fuel Co., McAlester, June 21; Chamber's lump coal.

26. Southern Fuel Co., McAlester, June 21; Hartshorne lump coal.

27. Southern Fuel Co., Dallas, September 4, 1911; screened pea from Brewer Coal & Mining Co.

28. Southern Fuel Co., Dallas, Texas, September 4, 1911; slack; from Brewer Coal & Mining Co.

29. Southern Fuel Co., Dallas, Texas, September 19, 1911; Midway McAlester coal.

We have also examined a sample of so-called McAlester slack, sampled at Austin, Texas, April 27, 1911. The analysis was as follows:

	As rec'd.
Moisture	3.70
Volatile combustible matter	27.09
Fixed carbon	44.93
Ash	24.28
	100.00
Sulphur	2.97
British thermal units, per pound	10,366

The following analyses represent samples of Oklahoma lump coal submitted to us for analysis:

	30. Per cent.	31. Per cent.	32. Per cent.
Moisture	2.00	1.12	1.00
Volatile combustible matter	35.78	37.12	37.00
Fixed carbon	58.33	58.61	57.70
Ash	3.89	3.05	4.30
	100.00	100.00	100.00
Sulphur	0.49	0.80	0.78
British thermal units, per pound	13,725	14,059	14,788

30. Buck McAlester lump.
31. Krebs McAlester lump.
32. Osage McAlester lump.

But coal that is termed "Oklahoma domestic lump," may depart very widely from the above composition, as the following analysis of a sample taken from a private residence in Austin, March 16, 1913, will show: This coal was bought for Oklahoma domestic lump and the price was $8.50 a ton. The analysis was as follows, as received:

	Per cent.
Moisture	1.84
Volatile combustible matter	34.60
Fixed carbon	46.20
Ash	17.26
	100.00
Sulphur	0.91
British thermal units, per pound	11,845

This coal contained 20 per cent of material that passed a ½-inch screen.

During the season of 1912-1913, between the dates November 20, 1912, and April 2, 1913, we made 41 analyses of samples of washed McAlester Chestnut coal delivered at the University Powerhouse, Austin, Texas. The analyses represent more than a thousand tons of coal and the average composition of this coal was as follows:

	As rec'd, per cent.
Moisture	1.86
Volatile combustible matter	34.88
Fixed carbon	56.36
Ash	6.90
	100.00
Sulphur	1.02
British thermal units, per pound	13,556

It is to be noted with respect to these analyses that the moisture in the coal as received is probably considerably higher than the results above given, for the samples were not delivered promptly to the laboratory and lost a good deal of water between the time of sampling and the time of delivery to the laboratory. In these analyses the following variations were noted:

Washed McAlester Chestnut.

	From, Per cent.	To, Per cent.
Moisture	....	4.00
Volatile combustible matter	24.56	45.96
Fixed carbon	46.04	66.24
Ash	3.00	16.20
Sulphur	0.29	2.48
British thermal units, per pound	11,705	15,305

It is also to be noted that the sample carrying 16.20 per cent of ash was, in all probability, not washed McAlester chestnut. Just what this coal was we are unable to say, but we do not believe that it was washed chestnut.

The following analyses of Oklahoma coal were made in our laboratory for the State Purchasing Agent, Austin, by J. E. Stullken, assistant chemist:

McAlester Lump

Samples from State Lunatic Asylum, Austin, Texas, November 30, 1912 to April 7, 1913. Average of 7 analyses, as received at laboratory:

	Per cent.
Moisture	4.08
Volatile combustible matter	35.94
Fixed carbon	53.49
Ash	6.49
	100.00
Sulphur	1.59
British thermal units, per pound	13,042

Samples from Deaf, Dumb and Blind Institute for Colored Youth, Austin, January 30 to April 18, 1913. Average of 6 analyses, as received at laboratory.

	Per cent.
Moisture	3.85
Volatile combustible matter	33.10
Fixed carbon	52.37
Ash	10.68
	100.00
Sulphur	1.97
British thermal units, per pound	12,314

Samples from Confederate Home, Austin, January 17 to March 24, 1913. Average of three analyses, as received at laboratory.

	Per cent.
Moisture	3.97
Volatile combustible matter	35.73
Fixed carbon	53.14
Ash	7.16
	100.00
Sulphur	1.94
British thermal units, per pound	12,582

The average of two samples of McAlester Mine Run, from the North Texas Hospital for the Insane, Terrell, January 3 and February 5, 1913, gave as received at laboratory:

	Per cent.
Moisture	3.25
Volatile combustible matter	30.00
Fixed carbon	52.20
Ash	14.55
	100.00
Sulphur	1.41
British thermal units, per pound	11,486

The average of four samples of McAlester Mine Run from the Southwestern Insane Asylum, San Antonio, January 7 to April 13, 1913, as received at the laboratory, was as follows:

	Per cent.
Moisture	2.96
Volatile combustible matter	34.40
Fixed carbon	49.04
Ash	13.60
	100.00
Sulphur	1.61
British thermal units, per pound	11,507

The average of fourteen samples of Dewar coal, Oklahoma, examined for the State Purchasing Agent during 1912-1913, gave the following, as received at the laboratory:

	Per cent.
Moisture	3.90
Volatile combustible matter	35.37
Fixed carbon	53.01
Ash	7.72
	100.00
Sulphur	1.95
British thermal units, per pound	12,690

CHAPTER IV.

DRY DISTILLATION OF TEXAS COALS.

We have investigated the coals mined in Texas with reference to their gas-producing and coking qualities, not at all for the purpose of saying the last word on the subject, but to ascertain whether any of them was suitable for gas-making.

There is not much coal used in Texas for gas-making, the total amount being less than 30,000 tons a year. None of this coal, however, is Texas coal, Oklahoma and Alabama supplying the demand. Of the two establishments that used Texas coal in producers, one has closed its producer plant and the other is now using oil-fired kilns.

By far the greater amount of city gas used in Texas is made by the Lowe system (water gas), or by a combination of water-gas and oil-gas.

The inquiry that was set on foot did not involve illuminating gas at all, but was restricted to fuel gas. The candle-power of the gas made from each coal was determined in an American Bunsen photometer, with single or double standard candles and an Argand burner. By use of a Welsbach mantle, candle-powers from 30 to 40 were observed. The equipment of the experimental gas plant consisted of a steel retort holding two pounds of coal, broken to $\frac{1}{4}$-$\frac{1}{2}$ inch and dried; pipe-condensers for water, ammoniacal liquor and tar, and galvanized iron boxes for holding the caustic lime for absorption of carbonic acid. The gas, after passing through a Wright meter, was conducted into a capacious tank, counterbalanced and water-sealed. The temperature within the retort was taken with an electric pyrometer (Chatelier, thermocouple). The wires were carried into the retort through a silica tube, tightly packed with asbestos. The temperature observed was that of the retort immediately above the coal; not the temperature of the coal itself; and was kept as near 600° F. as possible. Porter and Ovitz have shown[1] that the temperature of an electric furnace may be from 167° to 218° F. above that of the highest temperature reached by the coal, the difference being less as the temperature of the furnace rises.

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[1] Bur. Mines, Washington, Bull. 1, 1910, pp. 29-30.

From the containing holder the gas was piped to a Junkers Continuous Gas Calorimeter and to the photometer. The heat units in the gas were also calculated from the analysis, both sets of figures being given. For calculating the heat units the following factors were used: illuminants, 1,700; carbon monoxide, 315; hydrogen, 264; methane, 853; for 60° F. initial temperature and 328° F. final temperature. In many cases there was a substantial agreement between the observed and the calculated heat units.

TABLE V.

Results of Distillation Tests on Texas Coals. Analyses by S. H. Worrell.

Analysis No.	Yield of gas cubic feet per net ton.	Gas—Dry.									Coal—Dry.								
		Composition.					Specific Gravity.	Candle Power.	B. t. u. per cu. ft.		Proximate Analysis.				Ultimate Analyses.				B. t. u.
		Illuminants.	Carbon Monoxide.	Hydrogen.	Methane.	Nitrogen.			Obs.	Calc.	Volatile Combust. Matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Per Pound.
246........	7,480	2.2	14.8	49.3	27.6	6.1	.410	1.0	562	559	38.45	42.48	11.87	4.24	58.25	4.17	12.35	2.12	10,213
247........	5,966	2.6	5.1	54.4	29.7	8.2	.355	4.5	590	573	38.30	46.94	14.76	3.41	65.42	4.40	9.21	2.80	11,196
248........	7,320	5.5	2.1	42.0	43.9	6.5	.385	1.6	687	630	54.00	37.97	8.03	2.25	71.04	5.65	10.03	3.00	12,604
249........	6,935	2.4	12.0	42.0	35.9	7.7	.441	12.4	700	622	40.25	48.65	11.10	2.14	67.38	4.83	13.08	1.47	11,695
250........	6,601	1.6	12.0	44.4	37.2	4.8	.427	9.6	637	622	39.20	57.73	3.07	1.80	74.74	5.08	13.67	1.64	12,527
251........	6,926	1.5	1.9	54.0	29.1	13.5	.355	4.0	591	533	33.70	39.96	26.34	2.00	55.44	4.14	9.56	2.52	9,636
747........	5,967	1.0	12.2	44.7	30.8	10.1	.446	6.5	530	516	35.50	39.16	25.34	1.80	57.20	4.40	7.96	3.30	10,412
699........	7,113	2.2	13.4	50.2	27.4	6.0	.410	10.0	540	527	38.00	44.44	17.51	1.30	64.12	4.92	10.41	1.74	11,545
700........	5,787	2.0	9.4	41.6	27.4	16.8	.490	2.5	475	483	37.58	40.49	21.05	1.70	60.01	4.63	9.93	1.80	10,807
340........	6,600	5.4	11.8	40.3	39.0	3.5	.428	6.5	724	702	50.45	38.10	11.45	3.09	66.06	5.72	12.18	2.50	11,740
257........	7,780	1.8	5.2	42.2	41.2	8.2	.421	8.1	641	638	39.50	50.99	9.51	2.10	70.91	4.85	9.29	3.34	12,410
753........	6,110	0.4	20.8	46.4	24.2	7.6	.437	1.5	474	471	38.18	39.01	22.81	1.84	60.28	3.77	9.88	1.42	10,510
802........	7,147	5.4	6.6	43.6	36.2	8.2	.424	15.4	702	667	47.52	39.18	13.30	2.05	......	......	......	......	12,470
341........	8,112	3.0	4.5	50.8	34.2	7.5	.378	7.0	632	615	39.60	49.56	10.84	3.17	70.00	5.15	8.14	2.70	12,265
396........	5,752	3.8	7.5	52.1	33.5	3.1	.330	4.2	598	606	41.95	50.08	7.97	1.98	71.78	5.35	10.75	2.17	12,526
698........	7,058	1.0	14.2	49.7	24.4	9.7	.424	5.3	462	474	37.40	47.37	15.23	2.00	63.80	4.67	11.40	2.90	11,269
Average.	6,790	2.6	8.3	46.7	32.6	7.9	.410	7.1	596	577	40.59	44.50	14.38	2.30	61.02	4.48	9.86	2.21	11,489

Explanation of Table V.

246. Belknap Coal Company, Newcastle, Young county.
247. Bridgeport Coal Company, Bridgeport, Wise county.
248. Cannel Coal Company, Darwin, Webb county.
249. International Coal Mines Co., Eagle Pass, Maverick county.
250. International Coal Mines Co. "Special."
251. Olmos Coal Co., Eagle Pass, Maverick county.
744. Olmos Coal Co., washed pea.
699. Olmos Coal Co., washed egg.
700. Olmos Coal Co., washed nut.
340. Rio Grande Coal Co., Laredo, Webb county.
257. Santo Mining & Developing Co., Weatherford, Parker county.
753. Stewart Creek Coal Co., Jermyn, Jack county.
802. Santo Tomas Coal Co., Laredo, Webb county.
341. Strawn Coal Mining Co., Strawn, Palo Pinto county.
396. Texas & Pacific Coal Co., Thurber, Erath county.
698. Wise County Coal Co., Bridgeport, Wise county.

Note.—Numbers 257 and 753 represent coals that are not now mined.

In order to compare these results with those reached in the distillation of well known coals used in Texas for gas-making, an Oklahoma coal was selected.

McAlester pea coal gave 6,130 cubic feet of gas per net ton, with the following composition:

	Per cent.
Illuminants	1.60
Carbon monoxide	7.60
Hydrogen	43.00
Methane	45.00
Nitrogen (by diff.)	2.80

The specific gravity of the gas was 0.400, the observed heating power, per cubic foot, was 708, and the calculated heating power was 686. The candle-power was 7.0. The composition of the coal from which this gas was made was as follows:

	Dry, per cent.
Volatile combustible matter	36.87
Fixed carbon	58.81
Ash	4.32
	100.00
Sulphur	1.40
British thermal units, per pound	13,090

There was left in the retort 75 per cent of good coke.

In the operations, as conducted, it was not possible to deprive the coals entirely of their volatile combustible matter, and the amounts left in the residues from the retort varied from 1.91 per cent, as in the case of a Carboniferous coal from Palo Pinto county, No. 341, to 8.75 per cent, as in the case of a Cretaceous coal from Maverick county, No. 340.

Table VI gives the results of the analyses of the several residues, the percentage yield and the character of the residue, i. e., whether it was coke of fair quality or not.

TABLE VI.

Composition and Character of Residue Left in Retort after Distilling the Coals Represented in Table V.

No.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	British thermal units, per pound.	Residue.	
						Yield, per cent.	Character.
246 778	3.18	75.30	21.52	4.72	11,523	62.50	Did not coke.
247 739	5.16	71.8	23.0	3.34	11,084	62.50	Did not coke.
248 733	3.51	78.31	18.18	2.01	12,050	81.25	Coke fair.
249 734	8.75	73.80	17.45	0.73	11,530	62.40	Coke fair.
250 735	6.15	90.19	3.66	0.91	13,082	65.00	Coked feebly.
251 740	2.93	73.12	23.95	0.71	10,848	68.7	Did not coke.
699 764	2.22	69.38	28.40	0.64	10,327	68.0	Did not coke.
700 765	2.81	70.87	26.32	0.85	10,679	65.0	Did not coke.
340 737	8.11	73.63	18.26	1.35	11,664	62.5	Coke fair.

No.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	British thermal units, per pound.	Residue.	
						Yield, per cent.	Character.
257 736	2.52	85.16	12.32	1.76	12,414	68.8	Coke fair.
753 769	7.54	63.38	29.08	3.17	11,248	68.0	Did not coke.
341 742	1.91	81.06	17.03	2.95	11,914	68.7	Coke good.
396 738	2.47	83.41	14.12	1.38	12,090	75.0	Coke good.
698 741	2.47	79.44	18.09	2.23	12,083	68.0	Did not coke.
Average	4.26	76.35	19.39	1.91	11,610	6.76	

A study of Tables V and VI gives some very interesting results:

First. The highest yield of gas was not from a coal containing the largest amount of volatile combustible matter. The highest gas yield, 7,780 cubic feet per ton, was from a coal from Parker county, containing 39.50 per cent of this matter, whereas a coal from Webb county of 54 per cent (the highest percentage observed) gave 7,320 cubic feet of gas per ton. Each per cent of volatile combustible matter in the one coal gave 1.97 cubic feet of gas and in the other coal 1.36 cubic feet.

Second. The lowest yield of gas, 5,752 cubic feet, per ton, was not from a coal containing the lowest amount of volatile combustible matter. This particular coal, from Erath county, contained 41.95 per cent of this matter, whereas a coal from Maverick county of 33.70 per cent (the lowest percentage observed) gave 6,926 cubic feet of gas per net ton.

Third. The coal giving the highest heat value in the gas, viz., 724 B. t. u. per cubic foot, was from the Rio Grande Coal Co., Webb county, and the coal giving the lowest heat value in the gas, viz., 462 B. t. u. per cubic foot, was from Wise county, the yield of gas being, respectively, 6,600 and 7,058 cubic feet per net ton.

Fourth. The Carboniferous coals, Nos. 246, 247, 257, 753, 341, 396 and 698, contain, on the average, 39.05 per cent of volatile combustible matter and yield, on the average, 6,894 cubic feet of gas per net ton, with 566 B. t. u. per cubic foot.

The Cretaceous coals, Nos. 248, 249, 250, 251, 744, 699, 700, 341, and 802, contain, on the average, 41.8 per cent of volatile combustible matter and yield, on the average, 6,711 cubic feet of gas per net ton, with 621 B. t. u. per cubic foot.

Fifth. Of the seven Carboniferous coals, two (Strawn coal, Palo Pinto county, and Texas & Pacific coal, Erath county), gave a good coke; one, from Parker county, gave a fair coke, and four showed no coking qualities. Of the seven Cretaceous coals examined for coking qualities, three gave a fair coke, one coked feebly and three showed no coking qualities. The three Cretaceous coals giving a fair coke were from the Cannel Coal Co., and the Rio Grande Coal Co., Webb county; and the International Coal Mines Co., Maverick county.

Sixth. Three of the coals examined gave a fairly good candle-power gas. These were a coal from the Cannel Coal Company, Laredo district, Webb county, with 16 c. p.; a coal from the Santo Tomas Coal Company, Laredo district, with 15.4 c. p.; and a coal from the International Coal Mines Company, Eagle Pass, Maverick county, with 12.4 c. p. A coal from the Olmos Coal Company, Eagle Pass, gave 10.00 c. p.

These coals are all Cretaceous and gave a fairly good coke, with ash ranging from 13 to 18 per cent and sulphur from 2 to 2.25 per cent.

Seventh. The highest heat value, 12,604, expressed as British thermal units (B. t. u.) per pound, on dry basis, was observed in a coal from the Cannel Coal Co., Laredo, Webb county. Coal from the International Coal Mines Co., Eagle Pass, Maverick county; from the Texas & Pacific Coal Co., Thurber, Erath county; from the Santo Tomas Coal Co., Laredo; and from the Strawn Coal Mining Co., Strawn, Palo Pinto county, also contained more than 12,000 B. t. u.

On the average, the Carboniferous coals contain 11,484 B. t. u. per pound; and the Cretaceous coals, 11,493, on dry basis.

Eighth. On the average, the Carboniferous coals contain 13.28 per cent of ash, and the Cretaceous coals, 15.24 per cent.

Ninth. From these investigations it would appear that we have in this State coals that are well adapted to the manufacture of both illuminating and fuel gas and that from some of them a good metallurgical coke can be made, suitable for copper, silver and lead smelting. It may not be possible to meet the severe requirements for coke used in iron smelting, where the specifications as to strength, ash and sulphur are more rigid.

We have not investigated any of these coals with reference to the yield and quality of the tar and ammoniacal liquor. As some of them are high in nitrogen, it is likely that they would yield a liquor rich enough in ammonia compounds to render the manufacture of sulphate of ammonia attractive. But this method of utilizing by-products can be profitably applied only in comparatively large establishments, using from 10,000 tons of coal a year to 20,000 and upwards.

The coal that yielded a 16 candle-power gas contained 3 per cent of nitrogen and yielded 7,320 cubic feet of gas per net ton. From a ton of such coal it would be possible to obtain at least 25 pounds of sulphate of ammonia, worth 75 cents. A gas plant using 10,000 tons a year could produce $7,600 worth of this material, and 732,000,000 cubic feet of gas of more than 600 B. t. u. per cubic foot. In heat units this gas would compare very favorably with the natural gas now used in Texas, as also with the best oil or water gas.

CHAPTER V.

GAS.

The fuel gas used in Texas may be classed under two general headings, namely:

1. Manufactured

a. City gas.
b. Producer gas.

2. Natural.

1. Manufactured Gas: a. City gas:

During the year 1912, according to statistics gathered by the United States Geological Survey, the total quantity of fuel gas (city gas) sold in Texas was 787,898,000 cubic feet, of which 70,652,000 cubic feet, or about 9 per cent, was coal gas, and 717,246,000 cubic feet, or 91 per cent, were oil and water gas. The price per 1,000 cubic feet for the oil and water gas was $1.21, and for the coal gas $1.42.

The statistics since 1902 are incomplete, with respect to coal gas, as they were not obtained for the years 1906, 1909, 1910 and 1911. For the other seven years, inclusive of 1912, the total quantity of coal gas sold for fuel was 713,101,000 cubic feet, of an average value of $1.36 per 1,000 cubic feet. The following Table, No. VIA, gives the production and distribution of coal gas and by-products from coal since 1902, with the exception of the years just noted.

TABLE VIA.

Production and Distribution of Coal Gas and By-Products from Coal in Texas—1902-1912.
Arranged from Statistics of the United States Geological Survey.

Year.	No. of establishments.	Coal, carbonized, short tons.	Coke.		Tar.		Total quantity gas produced in M. cubic feet.	Gas sold for illuminants.		Fuel gas sold.		Fuel gas.	Total value of all gas sold.
			Yield, short tons.	Value per short ton.	Yield, gallons.	Value per gal. Cents.		Quantity in M. cubic feet.	Value per M. cubic feet.	Quantity in M. cubic feet.	Value per M. cubic feet.	Per cent of total.	
1902..........	9	15,257	9,162	$5.30	218,943	9.5	142,415	79,547	$1.82	47,942	$1.44	33.6	$ 214,479
1903..........	8	15,653	8,755	5.72	154,629	8.6	139,400	75,515	1.75	56,095	1.31	40.2	205,949
1904..........	9	16,560	10,114	6.02	185,364	7.5	149,975	60,512	1.76	78,677	1.34	52.5	211,962
1905..........	10	19,188	11,984	4.55	236,341	6.4	177,287	60,402	1.75	106,515	1.38	60.1	253,566
1907..........	7	28,282	12,049	4.68	225,394	5.6	251,233	53,281	1.66	167,886	1.33	66.8	312,792
1908..........	8	30,461	8,733	4.55	101,580	5.7	284,650	53,717	1.83	185,534	1.29	65.2	239,251
1912..........	4	9,581	2,548	4.88	88,680	5.3	90,220	3,697	1.30	70,652	1.42	78.3	105,038
Total and average...	....	134,982	63,345	$5.10	1,210,931	6.9	1,235,181	386,671	$1.69	713,101	$1.36	56.7	$1,543,037

The total amount of coal carbonized was 134,982 tons, from which there were produced 63,345 tons of coke, of an average value of $5.10 a ton; 1,210,931 gallons of tar, of an average value of 6.9 cents a gallon; 1,235,181,000 cubic feet of gas, of which 386,671,000 cubic feet, or 43.3 per cent, were sold for illuminating purposes, at $1.69 per 1,000 cubic feet, and 713,101,000 cubic feet, or 56.7 per cent, were sold for fuel purposes, at $1.36 per 1,000 cubic feet. The yield of gas for all purposes was 9,150 cubic feet per ton of coal and the total value of all gas sold was $1,543,037. The maximum amount of coal carbonized during any one year was 30,461 tons, in 1908. During this year there were sold 185,534,000 cubic feet for fuel purposes. In 1912, the amount of coal carbonized was 9.581 tons, and there were sold 70,652,000 cubic feet for fuel. No attempt is made in this State to utilize the ammoniacal liquor. Some of the tar is distilled for roofing and paving purposes, but this industry is not extensive.

An analysis of the tar produced by an establishment using McAlester District nut coal, from Oklahoma, has been made in our laboratory.

Analysis of Coal Tar from Oklahoma Coal.

Specific gravity 1.252

	Per cent.
Water	4.00
Free carbon	25.32
Ash in free carbon	0.40
Coke yield	38.08
Ash in coke	0.22

The distillation gave:

	Per cent.	Specific gravity.
Ammonia water	4.10	
Light oil	2.97	0.981
Intermediate oil	6.24	0.990
Heavy oil	11.84	1.090
Anthracene oil	5.51	
Pitch	68.39	
Loss	0.95	
Total	100.00	

The distillation of the light oil gave:

	Per cent.
Water	9.23
To 284 deg. F. (raw benzol I)	31.80
To 348 deg. F. (raw benzol II)	2.57
To 383 deg. F. (carbol oil)	17.90
Residue	37.90
Loss	0.60
Total	100.00

The distillation of the intermediate oil gave:

	Per cent.
To 284 deg. F.	0.60
To 348 deg. F.	0.58
To 383 deg. F.	12.15
To 428 deg. F.	56.60
Residue	28.10
Loss	2.07
Total	100.00

The distillation of the heavy oil gave:

	Per cent.
To 383 deg. F.	0.48
To 428 deg. F.	33.22
To 518 deg. F.	48.21
Residue	18.00
Loss	0.09
Total	100.00

From 1,000 gallons of this tar there could be recovered:

Commercial benzine, gallons	8
Solvent naptha, gallons	3
Heavy naptha, gallons	42
Wood preserving oils, including creasols, gallons	170
Napthalene, pounds	739
Pure phenol, pounds	32
Medicinal cresol, pounds	43
Technical cresol, pounds	15
Pitch, melting point 106 deg. F., pounds	7,100

During the last few months we have made a number of analyses of coal gas supplied to a Texas city of about 35,000 inhabitants. This gas is, for the most part, coal gas, but a little oil and water gas is mixed in. The average composition of this gas was as follows (23 analyses):

	Per cent.
Carbonic acid	5.5
Illuminants	7.4
Oxygen	0.9
Hydrogen	45.8
Carbon monoxide	9.6
Methane	19.8
Nitrogen (by diff.)	11.0
Total	100.0

During this period the average candle-power was 15 and the average British thermal units per cubic feet were 546, by Junkers Calorimeter. In this city the quantity of fuel gas sold in 1912 was about 68,000,000 cubic feet, at the following prices per 1,000 cubic feet:

		Amount.
Less than 10,000 cubic feet, $1.50	less 20 per cent	$1 20
From 10,000 to 20,000 cubic feet	net	1 00
20,000 cubic feet and more	net	0 90

On these terms, the cost of 100,000 cubic feet would be:

	Amount.
First 10,000 cubic feet	$13 00
Second 10,000 cubic feet	10 00
Remaining 80,000 cubic feet	72 00
Total	$95 00

This gives an average cost of 95 cents per 1,000 cubic feet. The maximum production of fuel gas in any one establishment during 1912 was 340,000,000 cubic feet, and the selling price was $1.00 per 1,000 cubic feet.

The United States Geological Survey has also collected statistics of the production and distribution of oil and water gas, in Texas, for the years 1905, 1907, 1908, and 1912. No statistics are available prior to the year 1905. The following Table, No. VIB, has been prepared from these statistics, and sets forth the number of establishments, the yield and value of the tar, the total quantity of gas produced, the distribution of the gas, whether sold for illuminating or fuel purposes, the quantity of fuel gas expressed as percentage of the total, and the total value of all gas sold. The returns in regard to the tar in 1908 are included with those from Florida, Louisiana and Mississippi and in 1912, with those from Alabama in addition.

NOTE.—The gas coke made from Oklahoma coal at a plant in Texas contains volatile combustible matter 3.32, fixed carbon 76.76, ash 16.52 and moisture 3.40. The sulphur was 1.28 and the B. t. u. per pound 11,322.

TABLE VIB.

Production and Distribution of Oil and Water Gas and By-Products in Texas—1905-1912.
Arranged from Statistics of the United States Geological Survey.

Year.	No. of establishments.	Tar.		Total quantity of gas produced in M. cubic feet.	Illuminating gas sold.		Fuel gas sold.		Fuel gas, per cent of total.	Total value of all gas sold.
		Yield in gallons.	Value per gallon. Cents.		Quantity in M. cubic feet.	Value per M. cubic feet.	Quantity in M. cubic feet.	Value of M. cubic feet.		
1905	7	23,900	5.0	231,992	93,511	$1.51	196,960	$1.40	61.2	$418,754
1907	10	102,781	2.7	591,644	191,529	1.35	335,849	1.27	56.8	686,106
1908	11	*558,714	2.7	671,360	286,206	1.27	306,458	1.27	45.7	754,732
1912	16	†668,702	2.5	1,149,840	303,559	1.19	717,246	1.21	62.4	1,231,923
Total and average	....	....	....	2,734,836	874,805	$1.28	1,556,513	$1.27	56.9	$3,091,515

*Includes also Florida, Louisiana and Mississippi.
†Includes also Alabama, Florida, Louisiana and Mississippi.

A study of this table shows that:

1. There were produced, during the years mentioned, 2,734,836,000 cubic feet of oil and water gas, as against 803,390,000 cubic feet of coal gas during the same period. The production of oil and water gas was more than three times as large as that of coal gas.

2. The quantity of illuminating gas sold was 874,805,000 cubic feet, at an average price of $1.28, as against 171,097,000 cubic feet of coal gas at an average price of $1,73 per 1,000 cubic feet.

3. The quantity of fuel gas sold was 1,556,313,000 cubic feet, at an average price of $1.27, as against 530,587,000 cubic feet of coal gas at an average price of $1.34.

4. The fuel gas expressed as percentage of the total ranged from 45.7 to 62.4, with a general average of 56.9, which is almost exactly the general average for the fuel gas made from coal, expressed as percentage of the total.

We have made a number of analyses of the oil and water gas supplied to a Texas city of about 35,000 inhabitants, the same as mentioned under coal gas, and have found the average composition to be as follows:

	Per cent.
Carbonic acid	2.3
Illuminants	10.1
Oxygen	0.9
Hydrogen	36.3
Carbon monoxide	28.0
Methane	6.8
Nitrogen (by diff.)	15.6
Total	100.0
British thermal units, per cubic foot	573

For comparing the composition of oil and water gas with that of coal gas, made in the same city and by the same company, we state the two together:

	Coal gas.	Oil and water gas.
Carbonic acid	5.5	2.3
Illuminants	7.4	10.1
Oxygen	0.9	0.9
Hydrogen	45.8	36.3
Carbon monoxide	9.6	28.0
Methane	19.8	6.8
Nitrogen (by diff.)	11.0	15.6
Total	100.0	100.0
British thermal units, per cubic foot	546	573

In the coal gas (with a small admixture of oil and water gas) the carbonic acid was 2.4 as much as in the oil and water gas; the oxygen was the same; the hydrogen was 1.26 as much, and the methane was 2.9 as much. In the oil and water gas, however, the illuminants were 1.39 as much as in the coal gas, and the carbon monoxide was 3 times as much. The British thermal units in the two gases were practically the same. These analyses are representative of those made over a period of three years.

In each case the British thermal units were made in a Junkers Continuous Gas Calorimeter of the latest design, and were not calculated from the analysis. Particular attention is called to this because of the variation in the British thermal units obtained by calculation, according to the factors used. Thus, if we take the following analysis, viz.:

	Per cent.
Illuminants	7.4
Hydrogen	45.8
Carbon monoxide	9.6
Methane	19.8

and calculate the heat units by the factors 1580 for illuminants, 324 for hydrogen, 324 for carbon monoxide and 1010 for methane (the factors used in some producer gas plants), we have B. t. u. 458, as against 546 by actual determination. If, for an initial temperature of 60 degrees F. and a final temperature of 328 degrees F., we take the factors 1700 for illuminants, 264 for hydrogen, 315 for carbon monoxide, and 853 for methane, we have B. t. u. 446. Again, if we take the factors 2000 for illuminants, 326 for hydrogen, 324 for carbon monoxide, and 1010 for methane, we have B. t. u. 528, as againset 546 by determination. In case the heat units have to be determined by calculation, when the sample of gas is not sufficient for the calorimeter, we use the following factors:

	Factors.
Illuminants	2,000
Hydrogen	326
Carbon monoxide	324
Methane	1,010

For securing considerable quantities of gas, we use a steel cylinder capable of holding 50 cubic feet under a pressure of 30 pounds.

The consumption of fuel gas in Texas for the year 1912 was about as follows:

	Cubic feet.
Manufactured gas (city gas)	787,898,000
Natural gas	7,470,373,000
Producer gas (made mostly from lignite)	3,250,000,000
Total	11,508,271,000

The figures for producer gas are approximate, but it is thought that the total consumption of fuel gas of all kinds during the year 1912 was between eleven and twelve billion cubic feet. The consumption during the year 1913 will probably be considerably larger.

Owing to the increasing cost of gas oil and, to some extent also, to local conditions, there is a tendency towards the manufacture of coal gas. One establishment which used a combination of the Lowe system and oil and which sold, in 1912, 68,519,000 cubic feet of fuel gas, has erected retorts for coal gas, using Oklahoma coal.

In most, if not all, of the cities and towns using manufactured gas, the illuminating and fuel gas are conveyed through the same pipes.

No statistics have been gathered as to the cost of manufacturing city gas in Texas, but it is likely that an average of 45 cents per thousand cubic feet is not far from the truth.

Manufactured gas is largely used for domestic purposes, whereas natural gas is largely used for industrial purposes. The heat units in the best natural gas are a good deal higher than in the best manufactured gas, but, as a general rule, there are only from 150 to 200 more B. t. u. per cubic foot in the natural gas used in Texas than in the manufactured gas. Many gas engines of comparatively small horse-power are operated on manufactured gas, but some of the gas engines operated on natural gas and lignite producer gas are of 1,000 horse-power.

The use of the candle-power as a standard for gas is of but little value in this part of the country and under the conditions that are likely to maintain. There is no longer any considerable illumination from gas direct, for the extensive introduction of the Welsbach and other 'mantles' has done away with the old-fashioned gas burners. The encroachments of electric lighting have also been a serious factor in the gas industry, especially since the introduction of the metallic filament. Acetylene, blau-gas, etc., have also added to the competition.

A striking illustration of the advantages to be derived from the use of an incandescent 'mantle' is shown by the fact that gas distilled from lignite can be made to yield an illumination equivalent to 40 candle power, although the gas itself has a very low candle power.

It is much to be desired that the "British thermal unit per cubic foot" should replace the "candle-power," as a standard for gas. When the British thermal unit per cubic foot is given, a statement should be made whether the figures are from direct determination in some accepted calorimeter or from calculation, the factors used being given in the latter case.

As the greater quantity of gas made or produced in Texas is used for fuel purposes, the change of the standard from candle-power to British thermal units per cubic foot would entail no hardships in the trade, upon producer or consumer.

Manufactured Gas:—b. Producer Gas.

Producer gas in Texas is made almost entirely from lignite, and the following pages give the chief points of interest in connection with this business. It will be seen that during the year 1912 there were used about 65,000 tons of lignite for this purpose, no attempt being made to save the by-products such as tar, ammoniacal liquor, etc.

The Use of Raw Lignite in Gas Producers.

In Bulletin No. 189, University of Texas, issued in 1911 and entitled "The Composition of Texas Coals and Lignites and the Use of Producer Gas in Texas," there was a special chapter on this subject, prepared by Drury McN. Phillips, who was in the producer-gas department of the Southwestern States Portland Cement Company, at Eagle Ford, near Dallas.

At that time there were in the State fifty-six producers for making gas and forty-seven in active operation, representing 12,270 horse-power. There were twenty-three establishments using Texas lignite exclusively, with a total consumption of about 180 tons per twenty-four hours and a total engine horse-power of 11,490.

Most of the installations were and are still of comparatively small size, as the three cement plants (at Eagle Ford, Harry and near San Antonio) represent 9,000 engine horse-power out of the total of 11,490. Since Bulletin No. 189 was issued, one large cement plant has changed from lignite producer gas to natural gas.

It does not seem to be necessary at this time to repeat the statistics gathered in 1911, so we shall merely give the items of chief interest and then discuss, briefly, the condition of the industry at the close of the year 1912. As the lignite area in Texas represents about one-half of the total known area in the United States, and as the production here is twice as great as from any other State, so the use of lignite in Texas for making producer-gas is largely in excess of such use in all of the other States combined. Texas leads the entire country in area, production and utilization of lignite.

In Bulletin No. 261, 1905, United States Geological Survey, there are given the results of using Texas lignites in gas producers at the fuel testing plant, St. Louis. These tests were under the care of Mr. Robert H. Fernald, now professor of mechanical engineering in the University of Pennsylvania. As we gave the results obtained in our Bulletin No. 189, above referred to, it is not necessary to repeat them here in detail and we shall merely quote the chief points of interest:

Lignite from the Houston County Coal and Manufacturing Company, Crockett, Houston county, gave 28.4 cubic feet of gas per pound of raw lignite consumed, in a No. 7 Wood producer, and this gas showed 169.7 B. t. u. per cubic foot. The average composition of the gas was:

	Per cent.
Carbonic acid	11.10
Carbon monoxide	14.43
Hydrogen	10.54
Methane	7.48
Nitrogen	56.22
Oxygen	0.22

Per brake horse-power developed at the engine there were consumed 2.54 pounds of lignite, on an assumed efficiency of 85 per cent for generator and belt.

Lignite from the Consumers Lignite Company, Hoyt, Wood county, gave 34.2 cubic feet of gas per pound of lignite and this gas showed 156.2 B. t. u. per cubic foot. The average composition of the gas was:

	Per cent.
Carbonic acid	9.60
Carbon monoxide	18.22
Hydrogen	9.63
Methane	4.81
Nitrogen	57.53
Oxygen	0.20

Per brake horse-power developed at the engine, there were consumed 1.98 pounds of lignite, on an assumed efficiency of 85 per cent for generator and belt.

In Bulletin No. 332, United States Geological Survey, 1908, there are given the results of producer gas tests on lignite from J. J. Olsen & Sons, Rockdale, Milam county. The yield of gas is not given, but the B. t. u. per cubic foot were 171.8. The composition of the gas was:

	Per cent.
Carbonic acid	10.3
Carbon monoxide	19.8
Hydrogen	14.8
Methane	2.4
Nitrogen	51.3
Oxygen	0.7
Ethylene	0.7

Per brake horse-power developed at the engine, there were consumed 2.17 pounds of lignite.

The Westinghouse Machine Company, Pittsburg, Pennsylvania, in its circular W. M. 503, September, 1909, gives the results of testing lignite from the Consumers Lignite Company, Hoyt, Wood county, as follows:

The total lignite fired was 16,970 pounds. The average load was 128 brake horse-power and the gross lignite per brake horse-power was 1.85 pounds. The gas was delivered through a line of 8-inch pipe over 650 feet long, with no correction for leakage or for gas consumed by three pilot lights burning continuously in the producer house, laboratory and engine room.

Another test made by this company on the same lignite showed a gas yield of 49.03 cubic feet of gas per pound of lignite fired, the gas giving 128.3 B. t. u. per cubic feet, total, and 117.1 B. t. u. effective. The composition of the gas was:

	Per cent.
Carbonic acid	12.4
Carbon monoxide	13.3
Hydrogen	14.7
Methane	3.6
Nitrogen	55.1

The Smith Gas Power Company, Lexington, Ohio, is authority for the statement that a certain plant using Texas lignite for an 80-horse-power installation saved $3.50 a day as compared with steam.

An irrigation pumping plant on the Nueces river, Nueces county, used lignite from the Bear Grass Coal Company, Jewett, Leon county, under a guarantee that one brake horse-power should be given by 2.50 pounds of lignite, the engine being rated at 225 horse-power.

A large cotton seed meal company in Houston used lignite from the Houston County Coal and Manufacturing Company, Crockett, Houston county. The specifications called for a gas of 140 B. t. u. per cubic foot and the engine was to deliver one brake horse-power for each 10,000 effective heat units. In this establishment the consumption of lignite was said to be 1.75 pounds per brake horse-power.

In a report made by Drury McN. Phillips and by permission of the Southwestern States Portland Cement Company, Eagle Ford, near Dallas, very complete returns were available in regard to operations there. Six Harvey producers were in use and two sets of figures were secured. In the first case, the total lignite charged was 116,280 pounds in twenty-four hours, or 4,845 pounds per hour; the lignite coming from the Consumers Lignite Company, Hoyt, Wood county, and costing $1.62 a ton, delivered. The total number of kilowatt hours was 16,330 (=21,882 horse-power hours) and the consumption of lignite was, on the average, 3.6

pounds per k. w. hour (=2.7 pounds per h. p. hour). The cost of the fuel was 2.18 mills per horse-power hour.

In the second case, the total lignite charged was 117,640 pounds in twenty-four hours, or 4,902 pounds per hour. The total number of kilowatt hours was 16,010 (=21,453 horse-power hours) and the consumption of lignite was 3.2 pounds per kilowatt hour (=2.4 pounds per horse-power hour).

Taking this test as a whole there were used 233,920 pounds (=116.96 tons) of lignite, with a production of 66,740 kilowatt hours (=89,411 horse-power hours), or a general average of 3.5 pounds of lignite per kilowatt hour (=2.6 pounds per horse-power hour). With lignite at $1.62, delivered, this represented a raw fuel cost of 2.83 mills per kilowatt hour (=2.11 mills per horse-power hour).

The B. t. u. per cubic foot, during the first run, varied from 106.3 to 139.9, the average being 119.8 During the second run, the B. t. u. per cubic foot varied from 116.0 to 138.0, the average being 127.1.

The average composition of the gas, during the two runs, was as follows:

	First run, per cent.	Second run, per cent.
Carbonic acid	10.8	10.3
Carbon monoxide	14.3	12.6
Hydrogen	8.1	8.7
Methane	3.5	4.8
Oxygen	0.6	0.5
Nitrogen	61.9	62.4
Ethylene	0.8	0.4

The heat units were determined by calculation, the factors used being for:

Carbon monoxide	324
Hydrogen	324
Methane	1010
Ethylene	1580

At this establishment the equipment consisted of six Harvey up-draft pressure producers and three 750 k. w. Allis-Chalmers horizontal two-cylinder tandem double-acting gas engines. On the main shaft there were Allis-Chalmers generators of 2,300 volts.

So far as could be ascertained, the consumption of lignite in

1911, for making producer gas, was about 180 tons a day. Several plants ran intermittently so that it is not likely that the total consumption of lignite during the year, for this purpose, exceeded 50,000 tons. If we allow that a ton of lignite yields 50,000 cubic feet of gas in a producer, we would have 2,500,000,000 cubic feet of gas from the 50,000 tons. If we allow, further, that this gas carried, on the average, 125 B. t. u. per cubic foot, we would have a total output of 312,500,000,000 B. t. u. for the year. This amount of heat would exaporate 32,000,000 pounds of water from and at 212 degrees F.

During the year 1912, so far as could be ascertained, the consumption of lignite in gas producers was about 65,000 tons, a gain of 15,000 tons, or 30 per cent over the returns for the year 1911. The delivery prices varied from 75 cents to $3.32 a ton according to quality and distance hauled.

One large consumer reports the use of 32,898 tons of lignite at $1.50 a ton, the yield of gas being 69,000 cubic feet per ton. Another reports the use of 7,600 tons at $1.60 a ton, and a calorimeter card, typical of the practice there, shows a gas of very uniform heat value, from 135 to 165 B. t. u. per cubic foot.

Lignite screenings, costing from 75 cents to $1.00 a ton, are also used in gas producers with satisfactory results.

There is practically no recovery of by-products in producer gas practice in Texas. At some of the plants the tar is burned under auxiliary steam boilers and at others a little tar is used for "creosoting" telephone poles, etc. No tar is distilled, nor is there any attempt to utilize the ammoniacal liquor.

It is not the custom here to meter the gas, so that there are but few reliable statistics as to the yield of gas per ton of lignite. One consumer, already referred to, reports the use of 32,898 tons of lignite during the year 1912, and says that the yield was 69,000 cubic feet per ton. This may be in excess of the average yield, but we have no means of ascertaining whether it is or not. For purposes of calculation, we would prefer to take 50,000 cubic feet of 125 B. t. u. gas per ton of lignite, and be on the safe side.

During the last year there has been considerable interest in the establishment of a central power plant located at or near some of the lignite mines and the matter has been looked into carefully.

The plans contemplated the erection of a modern producer gas plant, with recovery of by-products, such as tar and ammonia, and the wiring of electric power to cities, towns, cotton gins, irrigation installations, etc. From some of the lignites available, it would be possible to recover from 75 to 100 pounds of sulphate of ammonia per ton of lignite and this is worth from 2½ to 3 cents a pound, with a steady market all the year round.

If we allow that the 65,000 tons of lignite used in gas producers in Texas in 1912 could have yielded 50 pounds of sulphate of ammonia per ton (a very reasonable assumption) the total value of this salt, at 2½ cents a pound, would be $81,250.

Owing to the scattered locations of the producer plants it is impossible to recover the sulphate of ammonia from all of them, so we can confine the matter more closely.

The plant that used 32,898 tons of lignite could have recovered sulphate of ammonia to the value of $39,122.

The plant that used 7,600 tons could have recovered sulphate of ammonia to the value of $9,500, so that these two plants could have recovered $48,622 worth of this valuable material, all of which was lost.

A central power plant, using 200 tons of lignite a day, could produce, in one year, sulphate of ammonia to the value of $136,875, to say nothing of the value of the tar and the products obtainable from it by distillation. Furthermore, these estimates do not include the value of the electric current to be secured from generators operated by gas engines.

The value of this current would depend almost entirely upon the location of the plant with reference to power consumption, not with reference to population except as this may imply the consumption of electric power. Thus, in north and north central Texas, within 100 miles of large deposits of lignite, the population of twenty cities and towns is about 350,000; but we do not know what are the power requirements in this area, inclusive, not only of the cities and towns, but also of smaller rural establishments. Electric power is already supplied to the larger cities and towns, so that any new supply would have to compete with a business which is active and progressive. It is not as though one was going into new territory, unoccupied by electric plants, but he would have to invade a territory fairly well supplied at present. This could be done successfully only by providing cheaper power or more uniform and dependable power. With the recovery of valuable by-products from the central power plant, both of these requirements could be met, but without such recovery the investment does not appear to be attractive.

In 1909, the Consumers Lignite Company, Dallas, Texas, sent several carloads of Hoyt lignite to the Westinghouse Machine Company, East Pittsburg, Pa., for testing in gas producers. The following is the complete report, made by Mr. H. E. Longwell, consulting engineer:

"October 23, 1909.

We beg to report that the several carloads of Hoyt lignite, received from your company, have been carefully tried out in our testing plant at East Pittsburg to determine the question of the suitability of this fuel for use in gas producers, and the results have been highly satisfactory.

The gas was free from tar, and averaged 128.3 B. t. u. total, and 117.1 B. t. u. effective, per cubic foot, at 30 inches barometric pressure, and a temperature of 62 degrees F.

We have experienced no trouble with clinkering, and the labor required to operate the producer and keep the fires in good condition is noticeably less than with a coking coal. In fact, the operator must be cautioned *not* to poke the fire too much, as we have found that too zealous poking is not only unnecessary, but is absolutely deterimental in operating the producer with this fuel. As compared with Pocahontas, or any other high-grade bituminous coal, the value of your lignite for use in a gas engine and producer plant is practically in direct ratio to the British thermal units in a pound of the respective fuels.

This has been determined by comparative tests with Pocahontas coal made under the same conditions as the tests made with your lignite. Summaries of the tests are given below:

	Fuel.	
	Hoyt lignite.	**Pocahontas coal.**
Duration of test	46½ hours	72 hours
Total coal used	12,693 lbs.	10,699 lbs.
Average load of engine	151.5 brake h. p.	149.2 brake h. p.
Gross coal per brake-horse-power hour	1.8 lbs.	0.996 lbs.
B. t. u. per pound of coal	8,007	13,983
B. t. u. per brake-horse-power hour	14,412	13,927

In this case there is a variation of 3½ per cent in the number of British thermal units supplied per brake horse-power, but we should consider that this difference is well within the limit of agreement that we would expect between two tests made with the same kind of fuel.

Two other tests at approximately 125 horse-power show very much closer agreement:

	Fuel.	
	Hoyt lignite.	**Pocahontas coal.**
Duration of test	72 hours	48 hours
Total coal used	16,970 lbs.	6,403 lbs.
Average load of engine	128 brake h. p.	126.3 brake h. p.
Gross coal per brake-horse-power hour	1.85 lbs.	1.06 lbs.
B. t. u. per pound of coal	8,007	13,983
B. t. u. per brake-horse-power hour	14,812	14,821

From the foregoing tests it will be readily seen that with a suitably designed producer, the brake horse-power developed by the engine is only a matter of the number of British thermal units in the fuel supplied hourly to the producer, and it is immaterial whether this number of British thermal units is contained in a given quantity of Pocahontas coal averaging 14,000 B. t. u. per pound, or in a proportionately greater quantity of Hoyt lignite averaging only about 8,000 B. t. u. per pound.

We were somewhat fearful that the extra weight of lignite required to develop a given power might necessitate a proportionately larger producer than would be required for coal of a higher heat value. This we found not to be the case. As a large portion of the weight of the lignite consists of moisture and combustible matter that is already in a volatile state, the additional quantity of fuel charged hourly does not mean that the producer is really being worked with any greater intensity.

For your information we give below the comparative proximate

analyses of the Hoyt lignite, and Pocahontas coal tested, also comparative analyses of the gas from the two kinds of fuel:

Coal Analyses

	Hoyt lignite, per cent.	Pocahontas coal, per cent.
Moisture	23.83	1.39
Volatile matter	38.32	16.01
Fixed carbon	29.22	74.28
Ash	8.63	8.32
	100.00	100.00
B. t. u. per pound, by calorimeter	8,007	13,983

Gas Analyses

	Hoyt lignite, per cent.	Pocahontas coal. per cent.
Carbon dioxide	12.4	7.9
Oxygen	0.9	0.5
Carbon monoxide	13.3	18.1
Methane (marsh gas)	3.6	2.6
Hydrogen	14.7	12.6
Nitrogen	55.1	58.3
	100.0	100.0
Total heat value per cubic foot	128.3 B. t. u.	126.9 B. t. u.
Effective heat value per cubic foot	117.1 B. t. u.	117.8 B. t. u.

It is proper to add that the lignite as tested at our East Pittsburg plant had lost considerable of its moisture in transit, and in storage. With freshly mined lignite we should expect the B. t. u. value per pound to be less than in the samples tested, by reason of the probably higher moisture content, and as a consequence we should expect the fuel consumption per brake horsepower per hour to be proportionately higher than shown on our tests with the partially dry fuel.

However, this does not affect the main point of interest, i. e., that in a suitable type of producer this lignite can be utilized not only conveniently, but as efficiently in proportion to its actual thermal value as any fuel whatsoever."

As to the advantage of using producer gas, Mr. William Morey, Jr., has stated the matter in an excellent manner. He says[1]:

"The combined efficiency attainable in the best steam engines and boilers, operating under the most favorable conditions, is about

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[1] The Americana, Vol. IX, Article—Gas Producer.

12 per cent of the intrinsic heat energy of the fuel used. On the other hand, the modern gas engine, even in small powers, will give an efficiency much higher, but if it be supplied with illuminating gas for fuel, a large amount of the economy due to the higher efficiency is lost in the cost of the gas. Heat energy in the form of coal gas at a dollar per thousand feet, costs thirteen times as much as an equivalent amount of energy in the form of coal at three dollars per ton; therefore, in order to utilize a gas engine to its full advantage, the gas used must be produced as economically as possible. This is exactly the function of the gas producer, and by its use a good gas engine with a theoretical thermal efficiency of 75 or 80 per cent, or a practical thermal efficiency of 25 or 30 per cent, will readily convert into actual work, or available power, 25 per cent of the heat energy of the gas delivered to it. The gas producer of such a plant will transfer to the gas abount 80 per cent of the intrinsic energy of the coal, so that a gas-producer engine operating on an inferior grade of coal will show an efficiency of 20 per cent, as against the 12 per cent of a steam engine and boiler plant using the best steaming coal."

2. *Natural Gas.*

We first quote from "The Production of Natural Gas in 1912" advance chapter from the mineral resources of the United States calendar year 1912, United States Geological Survey, prepared by B. Hill under the supervision of David T. Day.

"The year 1912 was the best in the history of the natural-gas industry of Texas and the Clay county field was the greatest source of gas supply, the Lone Star Gas Company being the principal producer. This company does not distribute gas to consumers direct, but supplies its gas to the North Texas Gas Company, the Fort Worth Gas Company, the Dallas Gas Company, and the County Gas Company, which supply consumers. The following named places were supplied with gas from the Clay county gas field in 1912: Alvord, Arlington, Bellevue, Bowie, Bridgeport, Byers, Dallas, Dalworth, Decatur, Denton, Eagle Ford, Fort Worth, Grand Prairie, Henrietta, Irving, Petrolia, Rhome, Sunset, Wichita Falls.[1]

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[1] Additional towns supplied, October, 1913; Gainesville, Whitesboro, Sherman and Denison.

We are informed by the Lone Star Gas Co., Fort Worth, Texas, under

During 1912 a total of 13 wells were drilled in Clay county, of which eight were gas producers, the number of gas wells at the close of the year being 29. Although stray gas sands are occasionally struck at 1,250 to 1,500 feet, the best wells in this field range from 1,550 to 1,750 feet. The pressure varies from 600 to 742 pounds, the highest original rock pressure of wells in this field. The average pressure on January 1, 1912, was 659 pounds and on December 31, 1912, it was 626 pounds. One well in this field not in use during 1912 never fell below 730 pounds, and for five months stood at 740 pounds. A test of gas from a number of wells in the field made by S. H. Worrell, chemist for the Bureau of Economic Geology and Technology, University of Texas, shows 700 British thermal units per cubic foot.

Second in importance to the Clay county gas field is the gas field in Webb county (Reiser field) from whose wells gas is being supplied to consumers in the town of Laredo by the Border Gas Company, which receives its supply from the Producers Oil Company. Another gas field of importance is found in Shackleford county, (Moran field), from whose wells gas is being supplied to consumers in the town of Moran by the Pioneer Natural Gas Company and to the town of Albany by the Albany Natural Gas Company, both of these companies receiving their supply of gas from The Texas Company operating in this field.

Other fields in which developments were in progress in 1912 are as follows: In Angelina county a well was drilled to a depth of 312 feet, with a showing of oil and gas; work was discontinued and the well not finished. On Holloway Mountain, northwest part of Brown county, a gas well was drilled to a depth of 306 feet,

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date of October 29, 1913, that their pipe line mileage, in main and branch lines, is as follows, in round numbers:

2 inch line	17
3 inch line	5
4 inch line	43
6 inch line	42
8 inch line	14
10 inch line	40
12 inch line	50
16 inch line	155
	366

In addition to main and branch lines, there were between 15 and 20 miles of gathering lines, from 2 inches to 10 inches, in the field.

which furnished more than enough gas to operate an engine; another well drilled in this locality to a depth of 310 feet also furnished gas to run an engine. Two gas wells were drilled in Wichita county, gas being used for field purposes. In Gonzales county a gas well was completed at 468 feet, with 150 pounds pressure, product to be used in field work. There has been completed in Limestone county (Mexia field) three good, dry gas wells, having an estimated combined capacity of 40,000,000 cubic feet. In prospecting for oil in Maverick county, considerable gas was found in one well at depths of 725, 975, and 1,041 feet; in a second well only one gas stratum, at 941 feet, was discovered, this well not being drilled deeper. The first well at a depth of 725 feet has about 50 pounds pressure, and gas has been used from it for drilling. Two wells were drilling in McCulloch county at the close of 1912; four wells completed in this county in 1912 were abandoned. In Falls county an experimental well was drilled to a depth of 760 feet, with considerable showing of oil and gas; at a depth of about 160 feet it caved and shut out prospective findings. Coleman county was a field of activity in 1912, but up to the close of the year only two gas wells had been completed, the product of which was used for fuel in the field.

Considerable gas produced in the oil fields of Navarro and Harris counties is consumed for field purposes. Consumers in Corsicana are supplied with gas from Navarro county wells.

In Atascosa county several artesian wells have been drilled, which produce a small quantity of gas with the water. From a few of these wells, gas is being used by the owners of the wells for illuminating and heat.

The total quantity of gas produced from wells in Texas in 1912 amounted to 7,470,373,000 cubic feet, valued at $1,405,077, an average price of 18.81 cents per 1000 cubic feet as compared with 5,503,393,000 cubic feet, valued at $1,014,945, an average price of 18.44 cents per 1000 cubic feet, in 1911. This is a gain in value of $390,132. The greater portion of the value for 1912 was received for gas supplied for domestic purposes, which aggregated $906,412, or nearly double the value of the gas consumed for manufacturing and power purposes, which was $498,665. Some gas is used in Texas for brick manufacture. For power purposes it is utilized in operating gas engines and boilers at waterworks, ice plants, cotton gins, and also largely in field work.

The total number of gas wells in this State was 87 at the close of 1912, of which 24 were drilled in 1912. The number of dry holes drilled was 23, and the number of gas wells abandoned was six.

In the year 1908, there were 24 producers having natural gas wells, with 1,225 domestic, and 18 industrial consumers. In the years 1908, 1909, 1910, the amount of natural gas consumed and the value were combined with the returns from Alabama and Louisiana.

In the following table is given a record of the natural gas industry in Texas from 1909 to 1912, inclusive:

Record of Natural Gas Industry in Texas, 1909-1912.

Year.	Number of producers.	Number of consumers.		Total value of gas produced.	Wells.		
					Drilled.		Productive Dec. 31.
		Domestic.	Industrial.		Gas.	Dry.	
1909	17	2,322	52	$ 127,008	7	6	38
1910	19	14,719	133	447,275	22	5	52
1911	29	22,972	303	1,014,945	19	14	69
1912	41	27,226	329	1,405,077	24	23	87

The acreage controlled by natural gas companies in Texas, is shown by the following statement, taken from the volumes of the Mineral Resources of the United States, issued by the United States Geological Survey.

Acreage Controlled by Natural Gas Companies in Texas.

Year.	Fee.	Leased.	Gas rights.	Total.
1908	155	31,455	....	31,610
1909	1,845	19,653	131,597	153,095
1910	7,394	395,335	54,685	457,414
1911	3,740	153,379	361,739	518,858
1912	7,660	153,919	6,369	167,948

In any account of natural gas in Texas mention is to be made of the promising field at Crowther, northeast part of McMullen county, where the Boston and Texas Corporation has found excellent gas under good pressure. Our analysis No. 239 in Table VII gives the composition of this gas. It had high heating value, 947 B. t. u. per cubic foot.

We have made no analysis of the gas from the Mexia fields, Limestone county, but in a pamphlet issued by the Mexia Commercial Club it is stated that the heat units were 1,060 B. t. u. per cubic foot, on the authority of H. C. Morris, of the Dallas Gas Company.

Under date of November 3, we are informed by the Mexia Commercial Club that they now have 17 producers in that field, ranging in volume from two to fifteen million cubic feet per 24 hours, making approximately 150,000,000 cubic feet production per day. The pressure of the wells is uniformly 275 pounds to the square inch, and the depth varies from 650 to 725 feet.

The composition of natural gas from Texas is given in Table VII.

TABLE VII.

Composition of Texas Natural Gas—Analyses by S. H. Worrell.

Analysis No.	Carbon Dioxide.	Illuminants.	Oxygen.	Carbon Monoxide.	Hydrogen.	Methane.	Nitrogen (by diff.)	B. t. u. per cubic foot.	Specific Gravity.
362-367	......	......	......	......	......	......	......	700	......
144	None	None	2.2	None	None	50.3	47.5	503	......
243	None	None	None	None	None	56.0	44.0	649	......
502	None	None	None	None	None	85.4	14.6	862.5*	......
828	None	None	0.2	None	None	90.4	9.6	913	......
239	0.4	None	0.2	None	22.8	74.0	2.6	947*	0.458
166	None	None	1.4	1.2	None	34.8	62.6	300.5*	0.826
197	5.2	None	2.6	None	25.8	48.3	20.1	463*	......
696	None	None	None	None	None	80.8	19.2	835.5	......
852	None	None	None	None	None	92.0	8.0	929	0.588
311	None	None	Trace	None	None	85.2	14.8	726*	0.614
624	......	......	......	......	......	......	......	948	......
171	None	None	0.6	0.4	None	66.3	32.7	564*	......
Other Analyses.									
A	None	0.80	0.70	Trace	None	67.93	31.37	715*	......
B	0.20	0.30	0.40	......	0.80	47.2	38.6	474*	......
C	None	0.30	0.20	0.30	1.0	55.9	36.8	561*	......

Explanation of Table VII

Analyses Nos. 362-367, inclusive, represent heating power as examined in the gas from Petrolia, Clay county, for the Lone Star

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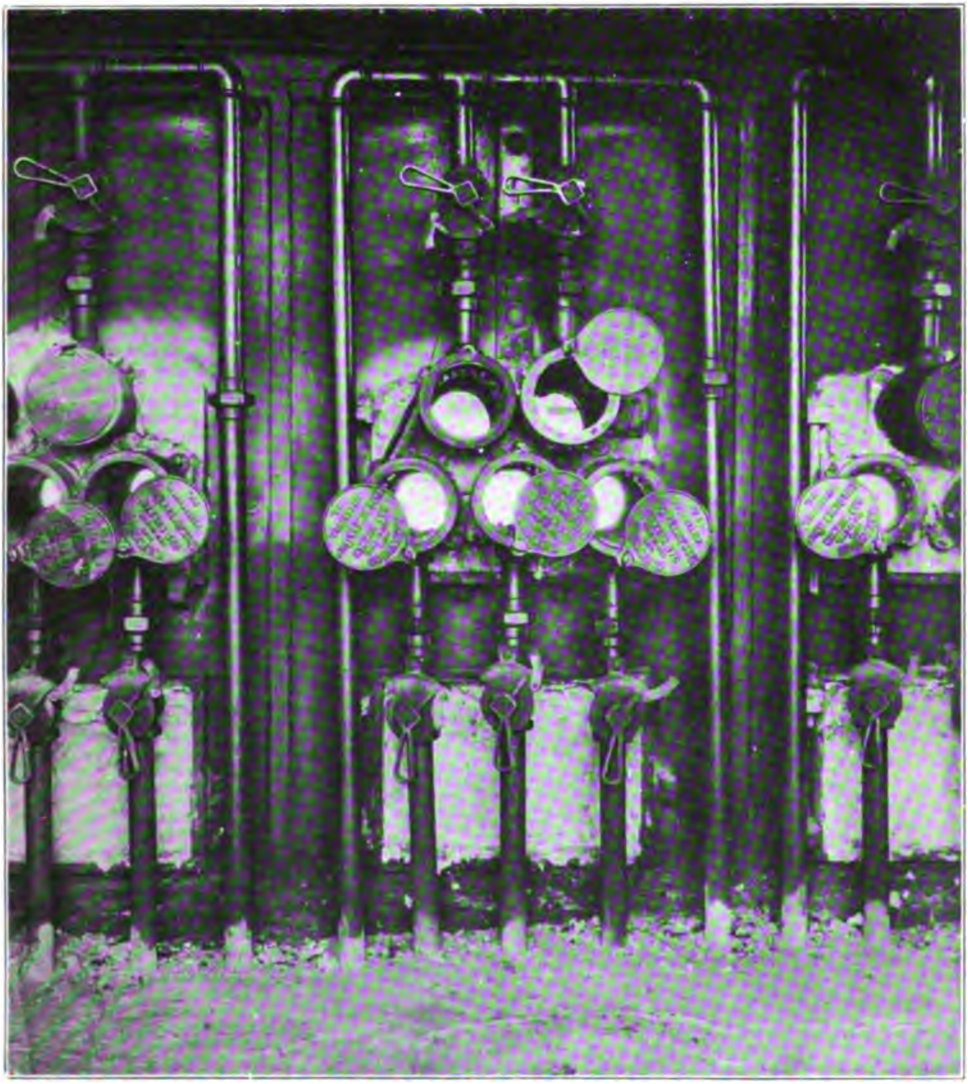
*Determined by calculation from the analysis, using the following factors: Illuminants, 1,700; carbon monoxide, 315; hydrogen, 261; methane, 853; for 0 deg. F. initial and 328 deg. F. final temperature. In analysis B there was reported 12.5 per cent. and in analysis C 5.50 per cent. ethane, which is not included in the calculation of thermal units.



Kirkwood Burners for Natural Gas. Wichita Falls Light & Water Co., Wichita Falls, Wichita County.

Gas Company, Fort Worth; the average of all tests being given.

No. 443, gas from Petrolia, Clay county; taken from the main in Fort Worth, and received by us in steel tank, January 9, 1913.

Analysis No. 243, gas from Petrolia, Clay county, from service pipes in Dallas, May 20, 1912.

Analysis No. 502, from a well nine miles west of Gonzales, Gonzales county.

Analysis No. 822, from a locality 14 miles west of Crockett, Houston county.

Analysis No. 239, from Crowther, McMullen county, Boston & Texas Corporation.

Analysis No. 166, depth of 712 feet, Fleming & Davidson well, Maverick county.

Analysis No. 197, gas bubbling up through Red River, at mouth of Cash Creek, Red River county.

Analysis No. 696, sample taken from gas line, 16 miles from the wells at Moran, Shackelford county. Lone Star Gas Company, Fort Worth.

Analysis No. 852, sample taken from a spring, 1 mile east of Trinity, Trinity county, Texas.

Analyses Nos. 311, 624, and 174, gas supplied to Laredo from Reiser, Webb county, by the Border Gas Company.

A. Gas from Petrolia, Clay county. Analysis by W. M. Russell, late city gas inspector, Fort Worth.

In our Bulletin No. 246, Oil and Gas Fields of Wichita and Clay Counties, page 283, this analysis is erroneously given. The figures for hydrogen should be those for methane, as Mr. Russell reported no hydrogen. We used the analysis that was sent to us, not, however, by Mr. Russell, and regret the error.

B. Gas from Petrolia, Clay county. Analysis by United Gas and Improvement Company, Philadelphia, September, 1909.

C. Same, November, 1910.

D. Gas from Caddo, Louisiana. Analysis by F. C. Phillips, Pittsburg, Pa. This gas is supplied to Texarkana, Marshall, Atlanta and Pittsburg.

In all of these analyses the B. t. u. marked * have been calculated by the factors given above. It is fair to say that other factors are used and that they give higher results than those we employed. We believe that the lower results will approach nearer commercial requirements than the higher ones. The B. t. u. not marked, were determined in the Junkers Continuous Calorimeter in our own laboratory.

According to statistics gathered by the United States Geological Survey, the total quantity of natural gas produced in the United States in 1912 was 562,203,452 M cubic feet, with an average value of 15.04 cents per M cubic feet. West Virginia led with a production of 239,088,068 M cubic feet. Texas ranked ninth in production and total value. In the quantity of natural gas consumed, Pennsylvania easily leads all of the other states, for, in 1912, it used 173,656,003,000 cubic feet, valued at $26,486,302, or 15.25 cents per thousand. In Pennsylvania the greatest consumption was for industrial purposes and the average value of the gas was 11.45 cents per M cubic feet. For domestic purposes, the average value per M cubic feet was 24.53 cents. A great deal of gas from West Virginia is piped to and consumed in Pennsylvania.

According to Poole,[1] the variation in, and the average composition of, 21 samples of natural gas from different localities in the United States, is as follows:

	From.	To.	Average.
Carbon dioxide	Trace	10.11	1.51
Illuminants	Trace	39.64	8.48
Oxygen	0.12	2.10	0.69
Carbon monoxide	Trace	1.00	0.48
Hydrogen	1.20	24.56	6.84
Methane	14.93	96.50	79.66
Nitrogen	2.96	27.84	4.83
Ethylene	0.15	18.12	2.77
Hydrogen sulphide	0.15	0.21	0.18
British thermal units per cubic foot	592	1,170	975

Of the 21 analyses given, eight contain hydrogen sulphide, in amounts varying from 0.15 to 0.18 per cent.

No gasoline is made from natural gas in Texas. This industry came into prominence in 1911 when there were produced in the United States 7,426,839 gallons valued at $531,704, or an average of 7.16 cents per gallon.

In this year the natural gas used for the manufacture of gasoline was 2,475,697,263 cubic feet, valued at $176,961; the yield of gasoline, per thousand cubic feet of gas, ranging from 2.68 to 3.56 gallons. Some kinds of natural gas yield from 8 to 10 gallons of gasoline per thousand cubic feet.

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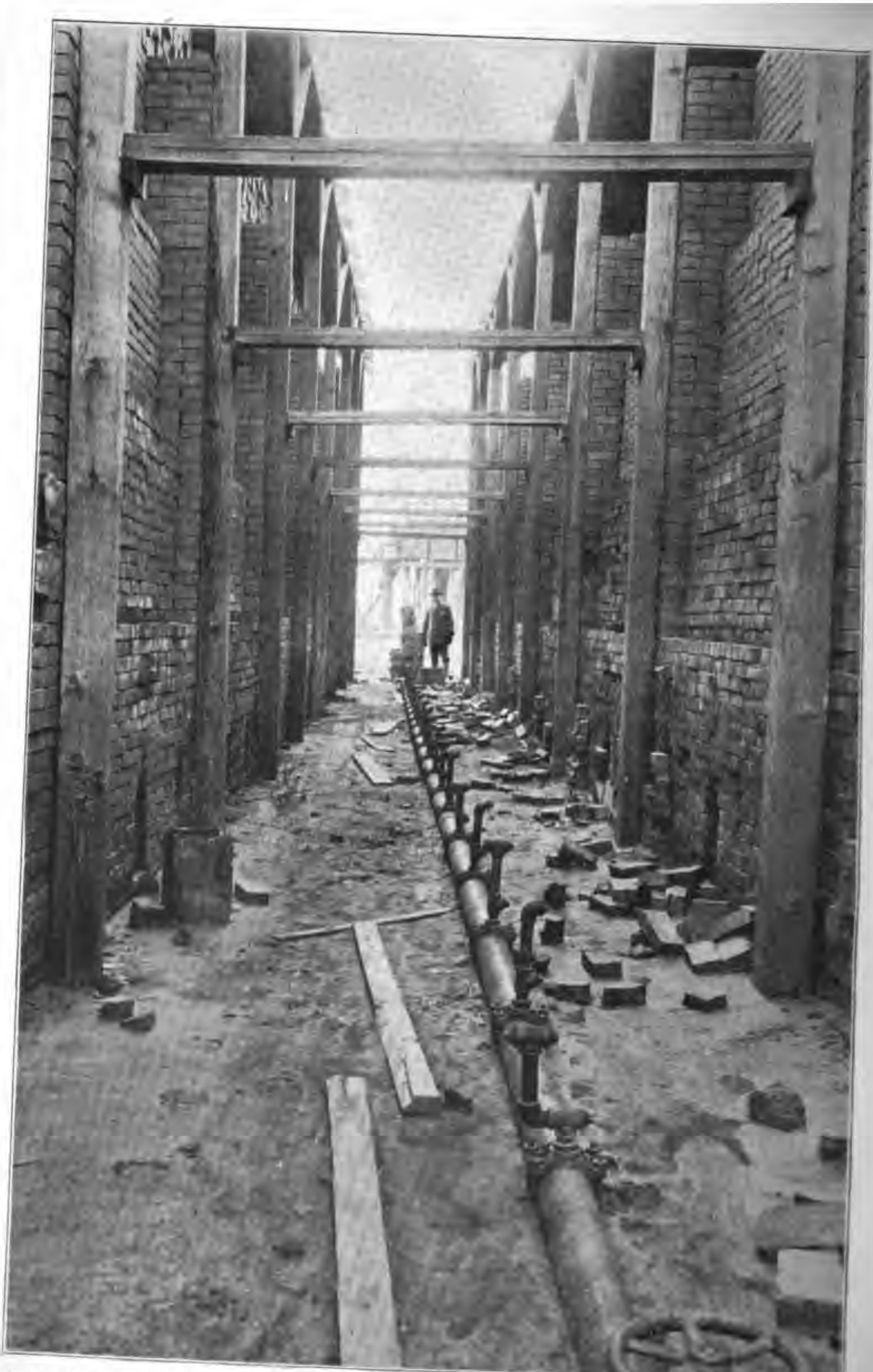
[1] The Calorific Power of Fuels, 2nd Ed., 1907.



Natural Gas Line at Plant of Northwestern Brick Co., Wichita Falls, Wichita County.

In 1912, the production of gasoline from natural gas rose to 12,081,179 gallons, valued at $1,157,476, or an average of 9.6 cents per gallon. The quantity of natural gas used was 4,687,796,329 cubic feet. As also in 1911, West Virginia was the largest producer of gasoline from natural gas, the other states, in order of rank, being, Pennsylvania, Ohio, Oklahoma, and California. The returns from Illinois, Colorado, New York and Kentucky were combined.

It might be possible to establish this industry in Texas, using natural gas or lignite gas, but the cost of such investigations has prevented us from working in this direction.

Natural gas at 9 cents per thousand cubic feet competes with lignite producer gas. There are two large establishments in the same immediate vicinity engaged in the same line of industry, and using about the same amount of power. One of them has natural gas, and the other lignite producer gas. The natural gas consumer formerly used lignite producer gas and changed to natural gas without, however, dismantling the producer plant.

The prices at which natural gas is sold are as follows:

In Dallas—net, minimum bill per month:

	Cents per 1,000 cubic feet.
First 10,000 cubic feet	45
Next 5,000 cubic feet	40
Next 15,000 cubic feet	35
Next 70,000 cubic feet	30
Next 900,000 cubic feet	20
All over 1,000,000 cubic feet	14

Boiler rates on term contract guaranteed minimum bill $60.00 a month:

First 250 M cubic feet, 20 cents per M cubic feet. All in excess of 250 M cubic feet, per month, 10 cents per M cubic feet. Boiler rates on yearly contract, guaranteed minimum bill $1,200 per annum—9 cents per M cubic feet.

In Wichita Falls natural gas is offered at 7 and even 6 cents per M. cubic foot, the piping distance from the wells in Clay county being from 15 to 20 miles.

In Marshall, which derives its natural gas from the Caddo fields, Louisiana, the following prices maintain, the piping distance being 25 to 30 miles:

Domestic rate, 25 cents per M. cubic feet, less 10 per cent if bills are paid on or before the tenth of the month following the purchase.

School and church rate, and for steam heating plants, 25 cents per M. cubic feet, net.

Factory rate, 15 cents, less than 250 M cubic feet.

Factory rate, 13½ cents, 250 M. to 500 M. cubic feet.

Factory rate, 12½ cents, 500 M. to 1,000 M. cubic feet.

Factory rate, 11 cents, 1,000 M. to 1,500 M. cubic feet.

Factory rate, 10 cents, 1,500 M. cubic feet and over.

For 30 days' consumption.

The gross sales in Marshall, for the fiscal year ending July 1, 1913, were 186,000,000 cubic feet for domestic and 426,000,000 cubic feet for industrial purposes.

In Fort Worth the prices are: Low pressure steam rate, heating only:

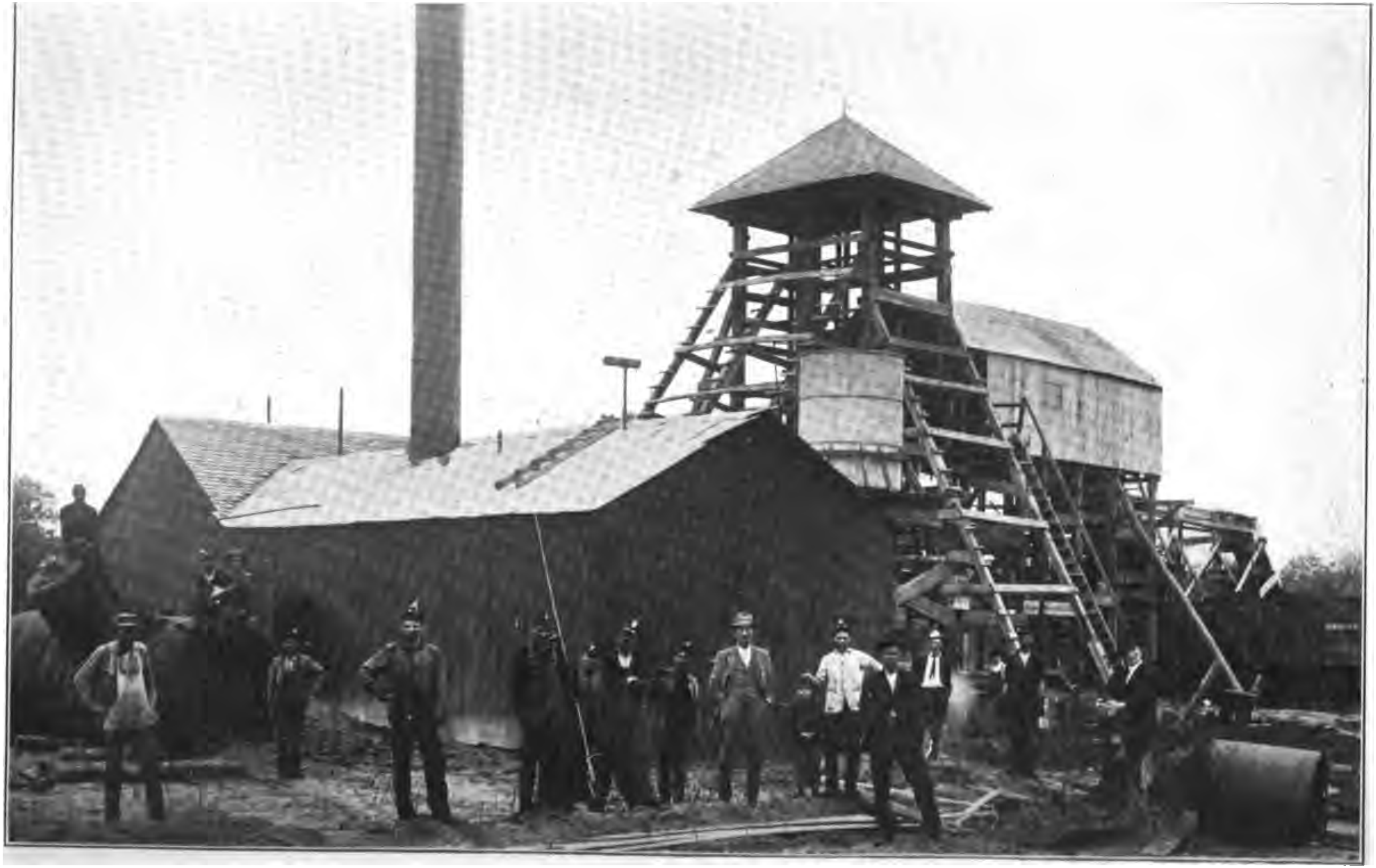
	Per 1,000 cu. ft.
First 250 thousand	25 cents, net.
All over 250 thousand	10 cents, net.
Industrial rate	9 cents, net.

In Texarkana, which uses natural gas from the Caddo fields, Louisiana, the net rates are 24 cents for domestic and 10 cents for industrial purposes per M. cubic feet. In 1912 there were sold in Texarkana 1,360,000,000 cubic feet, of which about 65 per cent was for industrial purposes.

Waco will soon have natural gas from the Mexia fields, Limestone county, and the price will probably be 50 cents per M. cubic foot for domestic purposes. The price of industrial gas will depend upon the amount consumed. The distance is about 45 miles.

Brownwood is to have natural gas from the Bangs field, Brown county, a distance of about 10 miles. The domestic rate will be 50 cents per M. cubic foot, but 15 cents for the use of the municipality.

Port Arthur now has natural gas from the Caddo field, Louisiana, utilizing an oil pipe line.



Como Lignite Mining Co., Como, Hopkins County.

CHAPTER VI.

LIGNITE.

Location and Extent of Fields—Composition.

In the United States there are about 127,200 square miles of lignite territory distributed as follows:

Alabama	6,000
Arkansas	5,900
Kentucky	500
Louisiana	8,800
Mississippi	3,000
Montana	7,000
North Dakota	31,000
South Dakota	4,000
Tennessee	1,000
Texas	60,000
Total	127,200

The lignite area in Texas comprises nearly one-half of the entire known area in the United States and is nearly as large as the entire State of Missouri.

The lignite fields of Texas probably extend over 60,000 square miles. The original supply of lignite may be taken to have been in excess of 30,000,000,000 tons and as it has scarcely been touched, the supply of this fuel need occasion no anxiety for the next thousand years or so. There is found in Texas every known variety of lignite, from a material carrying but a few per cent of fixed carbon to nearly 45 per cent, and with from 30 per cent of volatile combustible matter to more than 76 per cent.

Physically the lignites range from what is but little more than carbonized wood to a material almost like bituminous coal.

In thickness, the beds run to 15 feet and more, and they are found from the surface to depths of 400 to 800 feet.

The counties in which workable beds of lignite occur are the following: Anderson, Angelina, Atascosa, Bastrop, Bowie, Brewster, Caldwell, Camp, Cass, Cherokee, Dimmit, Fayette, Freestone, Grimes, Harrison, Henderson, Hopkins, Houston, Jasper, Lee, Leon, Limestone, McMullen, Marion, Medina, Milam, Morris, Nacogdoches, Newton, Panola, Rains, Robertson, Rusk, Sabine, San Augustine, Shelby, Smith, Titus, Upshur, Van Zandt, Webb, Wood and Zavalla.

The lignite-producing counties are: Bastrop, Fayette, Henderson, Hopkins, Houston, Leon, Medina, Milam, Rains, Robertson, Van Zandt and Wood.

In a general way, workable lignite is found in all that part of Texas lying east of the 97th meridian of west longtitude and north of the 31st degree of north latitude, but there are important areas outside of these boundaries.

In the year 1892 Mr. E. T. Dumble, State Geologist, issued a comprehensive and valuable report on Brown Coal and Lignite, and this still remains the chief source of information as to the geology and occurrence of lignite in Texas. In addition, many analyses are given and they are referred to in this Bulletin.

Mr. Dumble classed the brown coal (lignite) deposits as belonging to the Tertiary formation. They occur in the Gulf slope, from the Red River to the Rio Grande, in an area 650 miles in length and 200 miles in width. He says that the greater amount of the deposits are found in the Eocene series of the Tertiary and in the following divisions:

Fayette.
Yegua.
Timber Belt.

The lowest deposits are in the Timber Belt series, and this contains the heaviest and best beds. This series is especially developed in the counties extending southwest from Bowie county, on the Red River, such as Cass, Marion, Harrison, Morris, Titus, Hopkins, Camp, Upshur, Wood, Rains, Van Zandt, Smith, Henderson, Anderson, Freestone, Limestone, Leon, Robertson, Milam, Lee, Bastrop and Caldwell.

The Yegua division, including the lower portion of the Fayette beds, is divided into three sections, viz.: East Texas, Brazos river and Rio Grande.

The Fayette division of the Tertiary, comprising the uppermost beds of the lignite-bearing Eocene, he divides into four sections, viz.: East Texas, Brazos river, Colorado river, and Rio Grande.

As this Bulletin is not intended for any discussions of the geology of Texas coals or lignites, it is sufficient merely to call attention to the matter in a general way, and to refer those who desire detailed information to Mr. Dumble's "Brown Coal and Lignite."

Inasmuch as the development of the lignite industry in this State has come about since the publication of that excellent report and to a great extent because of it, more recent and more detailed analyses of the lignites mined and in use were undertaken by the University Mineral Survey in 1901-1902. These were published in Bulletin No. 2 of that survey, but this has long been out of print.

At that time samples were taken, in person, at the mines and were placed in tight cans, which were sealed. In this may the moisture in the lignites, as mined, was capable of accurate determination.

The mines visited and sampled were as follows:

No. 1535. Carr Mine, Lytle, Medina county.
No. 1536. Bertetti Mine, Lytle, Medina county.
No. 1537. Glenn-Belto Mine, Bishop, Bastrop county.
No. 1538. Worley Mine, Rockdale, Milam county.
No. 1539. Black Diamond Coal Co., Rockdale, Milam county.
No. 1540. Lignite Eggette Coal Co., Rockdale, Milam county.
No. 1541. J. J. Olsen & Sons, Rockdale, Milam county.
No. 1542. Big Lump Coal Co., Rockdale, Milam county.
No. 1543. Aransas Pass Lignite Co., Rockdale, Milam county.
No. 1544. Central Texas Mining, Manufacturing & Land Co., Calvert Bluff, Robertson county.
No. 1545. Houston County Coal Co., near Lovelady, Houston county.
No. 1546. Timpson Coal Co., Timpson, Shelby county.
No. 1547. North Texas Coal Co., Alba, Wood county.
No. 1548. North Texas Coal Co., Alba, Wood county.
No. 1549. Como Coal Co., Como, Hopkins county.

The production of lignite at that time and year by year since is given in the Table of Production of Coal and Lignite on page— of this Bulletin.

The analyses made on the samples taken in 1901-1902 are as follows:

TABLE VIII.

Composition of Texas Lignite, Sampled at Mines by University Mineral Survey, 1901-1902.

Analyses by O. H. Palm and S. H. Worrell.

Analysis No.	Proximate Analysis.									Ultimate Analysis.								Heat Value.		Specific gravity	Weight per cubic foot—Dry.
	Natural condition.					Dry basis.				Natural condition.				Dry basis.				British thermal units per pound.			
	Moisture.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Natural condition.	Dry basis.		
1535..........	35.30	36.33	28.85	7.52	0.93	56.15	32.24	11.61	1.45	41.36	3.07	10.76	1.04	63.93	4.75	16.64	1.62	7,903	12,215	1.28	80.0
1536..........	34.29	40.31	18.50	6.90	1.20	61.36	28.17	10.47	1.84	41.01	3.25	13.82	0.73	61.03	4.85	20.57	1.00	7,536	11,470	1.42	88.7
1537..........	35.40	36.88	21.22	6.50	0.94	56.94	32.86	10.20	1.47	42.24	3.13	10.67	1.00	65.40	4.85	16.52	1.56	7,859	12,166	1.30	81.8
1538..........	32.79	37.09	22.91	7.21	1.18	55.20	34.10	10.70	1.76	41.01	3.25	13.82	0.73	61.03	4.85	20.57	1.09	7,763	11,551	1.32	82.5
1539..........	34.72	34.26	22.73	8.29	1.04	54.02	34.82	11.16	1.60	41.93	3.12	11.03	0.85	64.24	4.79	16.90	1.31	7,697	11,792	1.20	75.0
1540..........	32.27	44.30	15.26	8.17	2.31	65.41	22.54	12.05	3.42	38.56	2.85	14.85	0.96	56.94	4.22	21.94	1.43	7,383	10,901	1.37	85.6
1541..........	33.63	46.78	7.45	12.14	0.99	70.49	11.24	18.27	1.50	38.78	2.70	10.89	0.86	58.44	4.07	16.42	1.30	7,359	11,088	1.37	85.6
1542..........	31.52	44.49	17.48	6.51	0.93	64.98	25.57	9.45	1.36	41.15	3.36	14.68	0.86	60.10	4.91	22.91	1.27	8,046	11,750	1.39	86.9
1543..........	29.07	28.96	24.47	7.60	3.29	40.84	34.49	24.67	4.65	38.65	2.73	7.32	1.40	54.51	3.86	10.33	1.98	7,439	10.489	1.44	90.0
1544..........	29.86	51.00	10.00	9.14	0.91	72.72	14.26	13.02	1.30	43.17	3.29	12.78	0.83	61.56	4.70	18.23	1.19	7,929	11,305	1.39	86.8
1545..........	36.16	33.16	19.93	10.75	0.40	51.95	31.26	16.70	0.64	34.93	3.17	13.69	0.89	54.73	4.98	21.46	1.40	7,518	10,994	1.35	84.4
1546..........	31.96	39.53	23.05	5.46	1.46	58.10	33.89	8.05	2.16	43.85	3.32	13.05	2.16	64.45	4.89	19.19	1.26	8,053	11,837	1.46	91.2
1547..........	35.00	45.21	11.60	7.59	0.47	70.21	18.02	11.77	0.73	40.06	2.91	12.01	1.41	62.12	4.52	18.66	2.20	7,567	11,751	1.16	72.5
1548..........	34.23	41.74	19.85	4.87	0.56	63.47	70.19	6.34	0.86	42.27	2.87	14.83	1.05	64.27	4.37	22.55	1.61	7,691	11,694	1.33	83.1
1549..........	33.87	45.88	3.41	16.84	0.68	69.39	5.16	25.45	1.04	34.05	2.30	11.15	1.09	51.50	3.49	16.87	1.65	6,474	9,790	1.18	73.7
Average.......	33.37	40.39	17.24	9.00	1.12	60.61	25.88	13.51	1.68	40.13	3.03	12.29	1.18	60.23	4.55	18.45	1.47	7,614	11,427	1.33	83.1

The variations in these analyses are as follows: Material as mined—

	From.	To.	Average.
Moisture	29.07	36.16	33.37
Volatile combustible matter	28.96	51.00	40.39
Fixed carbon	3.41	24.47	17.24
Ash	4.87	17.60	9.00
Sulphur	0.40	3.29	1.12
Carbon	34.93	43.85	40.13
Hydrogen	2.30	3.37	3.03
Oxygen	10.67	14.85	12.29
Nitrogen	0.85	1.41	1.18
Heating power, B. t. u., per pound	6,474	8,053	7,614
On dry basis these become:			
Volatile combustible matter	40.84	72.72	60.61
Fixed carbon	5.16	34.82	25.88
Ash	6.34	25.45	13.51
Sulphur	0.64	4.65	1.68
Carbon	51.50	65.40	60.23
Hydrogen	3.49	5.13	4.55
Oxygen	10.33	22.91	18.45
Nitrogen	1.09	2.20	1.47
Heating power, B. t. u., per pound	9,790	12,215	11,427
Specific gravity	1.16	1.44	1.33
Weight per cubic foot, pounds	72.5	90.0	83.1

TABLE IX.

Composition of the Ash of Texas Lignites.

Analysis No.	Silica.	Alumina.	Oxide of iron.	Lime.	Magnesia.	Oxide of Manganese.	Sulphuric acid.
1535	63.40	12.27	5.95	None	Trace	1.00	13.71
1536	40.46	16.92	8.32	15.60	1.22	....	15.54
1537	30.14	13.48	11.70	23.59	0.88	3.32	14.22
1538	21.64	16.20	11.10	25.23	4.36	2.00	18.01
1539	33.06	16.77	8.47	23.08	1.38	Trace	17.10
1540	27.44	28.87	24.85	7.00	Trace	0.52	10.45
1541	23.20	11.94	5.08	38.17	1.00	1.60	7.79
1542	42.20	23.02	2.02	15.93	2.12	Trace	12.81
1543	47.04	23.18	18.32	6.64	Trace	Trace	4.58
1544	40.60	34.26	2.02	12.08	Trace	....	9.52
1545	59.00	20.11	3.69	10.58	0.48	0.48	5.47
1546	25.64	19.08	12.92	18.68	1.76	....	20.92
1547	38.73	23.00	6.00	24.11	Trace	Trace	8.51
1548	33.00	25.84	7.40	22.32	....	....	11.32
1549	53.04	24.68	7.70	10.59	Trace	Trace	3.58
Average	38.57	20.64	9.04	16.84	0.94	0.81	12.90

In these lignites the following variations in the composition of the ash are to be noted.

	From.	To.	Average.
Per cent of ash	4.87	17.60	9.00
Silica	21.64	63.40	38.57
Alumina	11.94	34.26	20.64
Oxide of iron	2.02	24.85	9.04
Lime	0.00	38.17	16.84
Sulphuric acid	3.53	20.92	12.90

With the lignites, as with the coals, there is a considerable variation in the composition of the ash, leading to the conclusion that the conditions, with respect to vegetation and the in-wash of sediments, varied within wide limits.

On comparing the composition of the ash of these lignites with that of the coals given on page 16 it is seen that the lignite ash carried considerably less silica, alumina, and oxide of iron than the coal ash, but considerably more lime and combined sulphuric acid.

What deductions may be made from these facts does not now appear except that it is probable that the vegetation forming the coal was different from that forming the lignite, and also that the in-wash of extraneous materials was different during the process of the formation of these beds.

Whether the coal and lignite beds have been formed "in situ" or by "drift," or by a combination of these two methods is an open question. It is likely that conditions varied a good deal not only in the coal period as a whole, but also locally, and, to some extent, while the same seam was being made.

The analyses that have so far been given and discussed represent samples of lignites that were secured from the mines by an agent of the University Mineral Survey in 1901-1902.

In order to bring the matter down to date and present new and detailed analyses, the operating companies were asked to send in typical samples of the material they were mining and shipping. These samples were, for the most part, received in tin cans, with close-fitting covers. In those cases in which the moisture runs much below the normal the samples did not come in such cans, and, therefore, show a less amount of moisture than is usually found in our lignites.

As the analyses are given on the samples "as received," and on the dry, or waterfree basis, also they may readily be compared with each other.

The analyses of these "Company samples" are as follows:

TABLE X.

Analyses of Texas Lignites—Company Samples. By S. H. Worrell, 1910-1911.

Analysis No.	As Received.									Dry Basis.								Heating Power.	
	Proximate Analysis.					Ultimate Analysis.				Proximate Analysis.				Ultimate Analysis.				British thermal units, per pound.	
	Moisture.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	As Received.	Dry Basis.
40	29.28	34.02	29.04	6.66	.57	39.61	3.08	19.71	1.09	48.10	41.05	10.85	.80	56.00	4.35	26.48	1.54	7,238	10,220
59	15.00	43.61	32.71	8.68	.94	49.47	3.58	20.95	1.38	51.30	38.48	10.22	1.10	58.20	4.21	24.65	1.62	8,789	10,340
12	29.94	39.03	21.09	9.94	.55	37.70	2.93	17.48	1.46	55.70	30.09	14.31	.78	53.80	4.18	24.95	2.08	6,291	8,979
57	7.30	45.62	36.65	10.43	.51	58.78	4.43	16.37	2.18	49.21	39.53	11.26	.45	63.40	4.78	17.76	2.35	10,411	11,130
13	29.96	41.68	22.24	6.12	.70	44.01	2.88	14.76	1.57	59.50	31.75	8.75	1.00	62.77	4.11	21.14	2.23	6,903	9,855
14	22.40	42.68	24.77	10.15	.55	45.34	3.85	16.00	1.71	55.00	31.91	13.09	1.33	58.42	4.96	20.00	2.20	8,156	10,510
16	24.36	33.89	25.64	16.11	.74	42.13	3.60	11.76	1.30	44.80	33.89	21.31	.97	55.69	4.75	15.57	1.71	7,068	9,344
41	36.64	28.33	27.02	8.01	.41	36.16	2.79	15.02	.97	44.70	42.63	12.67	.64	57.06	4.40	23.70	1.53	6,717	10,600
17	29.20	36.92	27.02	6.86	.58	43.29	3.37	15.49	1.21	52.14	38.22	9.64	.81	61.14	4.75	21.95	1.71	7,442	10,510
56	10.80	41.20	38.92	9.08	.61	48.80	2.81	25.99	1.91	46.18	43.63	10.20	.68	54.70	3.15	29.13	2.14	9,670	10,840
18	31.24	40.29	21.07	7.40	.73	39.73	3.23	16.30	1.37	58.60	30.64	10.76	1.05	57.77	4.70	23.74	1.98	6,727	9,782
36	27.20	40.90	27.09	4.81	.48	44.72	3.73	17.92	1.14	56.18	37.20	6.62	.65	61.42	5.12	24.63	1.56	7,682	10,540
20	25.58	39.37	25.30	9.75	.60	42.57	3.99	16.12	1.39	52.90	33.99	13.11	.80	57.20	5.36	21.67	1.86	7,532	10,120
21	37.26	31.85	24.81	6.08	.57	38.10	3.16	13.74	1.09	50.76	39.54	9.70	.90	60.72	5.03	21.92	1.73	6,416	10,226
22	27.50	35.20	27.30	10.00	.73	43.20	3.12	14.48	.73	48.54	37.65	13.81	1.00	59.58	4.29	19.99	1.33	7,040	9,709
23	31.12	33.95	22.66	12.27	.93	39.04	3.24	12.48	.93	49.28	32.90	17.82	1.34	56.67	4.70	18.14	1.33	6,688	9,709
55	12.60	44.75	33.90	8.75	.63	56.34	3.99	16.64	1.05	51.20	38.78	10.02	.72	64.20	4.56	19.30	1.20	9,774	11,182
44	12.62	37.91	36.21	13.26	.48	50.18	3.53	17.90	2.05	43.38	41.43	15.19	.54	57.42	4.03	20.48	2.34	9,525	10,900
28	30.20	33.23	28.84	7.73	.69	42.72	2.84	14.36	1.46	47.60	41.31	11.09	.98	61.20	4.06	20.58	2.09	6,920	10,030
25	30.34	34.14	30.66	4.86	.61	42.10	3.33	17.56	1.20	49.00	44.00	7.00	.87	60.47	4.78	25.20	1.70	6,797	9,957
26	25.64	35.55	30.28	8.53	.96	43.00	3.45	17.17	1.25	47.80	40.71	11.49	1.29	57.82	4.63	23.09	1.68	7,459	10,030
39	20.64	36.24	32.64	10.48	.70	46.70	3.54	15.95	1.99	45.66	41.12	13.22	.80	58.81	4.46	20.21	2.50	8,262	10,410
29	32.12	34.30	26.61	6.97	.82	40.16	2.60	15.57	1.76	50.52	39.20	10.28	1.20	59.16	3.82	22.96	2.58	6,690	9,855
Average	25.17	37.59	28.45	8.79	.65	44.08	3.35	16.49	1.47	50.48	37.81	11.71	.90	58.85	4.48	22.20	1.86	7,661	10,212

The key to these "Company samples" is as follows:

Analysis No.	
40.	Alba Lignite Co., Alba, Wood county.
59.	Alba-Malakoff Lignite Co., Alba, Wood county.
12.	American Lignite Briquette Co., Big Lump, Milam county.
57.	American Lignite Briquette Co., Big Lump, Milam county.
13.	Bear Grass Coal Co., Jewett, Leon county.
14.	Bertetti Coal Co., Lytle, Medina county.
16.	Carr Wood & Coal Co., Lytle, Medina county.
41.	Como Lignite Co., Como, Hopkins county.
17.	Consumers' Lignite Co., Hoyt, Wood county.
56.	Consumers' Lignite Co., Hoyt, Wood county.
18.	Cookville Coal & Lumber Co., Mt. Pleasant, Titus county.
36.	Edgewood Coal & Fuel Co., Wills Point, Van Zandt county.
20.	Houston County Coal & Manufacturing Co., Crockett, Houston county.
21.	Independence Mining Co., Phelan, Bastrop county.
22.	Lone Star Lignite Mining Co., Como, Hopkins county.
23.	Melcher Coal & Clay Co., O'Quinn, Fayette county.
55.	Rockdale Coal Co., Hicks, Lee county.
44.	Rockdale Consolidated Coal Co., Rockdale, Milam county.
28.	Rockdale Lignite Co., Rockdale, Milam county.
25.	Rowlett & Wells, Rockdale, Milam county.
26.	Southwestern Fuel & Manufacturing Co., Calvert, Robertson county.[1]
39.	Texas Coal Co., Rockdale, Milam county.
29.	Vogel & Lorenz, Rockdale, Milam county.

Note.—The Alba-Malakoff Lignite Company is successor to the Alba Lignite Company. The Vogel Coal & Manufacturing Company is successor to Vogel & Lorenz.

Analysis No. 44, Rockdale Consolidated Coal Company, represents lignite sampled at the works of the Austin White Lime Company, McNeil, Travis county, January 13, 1911.

The variations in these analyses are as follows:

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[1] Now Southwestern Fuel Company. Main office in Waco.

Samples as Received.

	From.	To.	Average.
Moisture	7.30	37.26	25.17
Volatile combustible matter	20.33	45.62	37.59
Fixed carbon	21.09	38.92	28.45
Ash	4.81	16.11	8.79
Sulphur	0.41	0.96	0.65
Carbon	36.16	58.78	44.08
Hydrogen	2.60	4.43	3.35
Oxygen	11.76	25.99	16.49
Nitrogen	0.73	2.18	1.47
Heating power, B. t. u., per pound	6,291	10,411	7,661
On a dry basis these become:			
Volatile combustible matter	43.38	59.50	50.48
Fixed carbon	30.09	44.00	37.81
Ash	6.62	21.31	11.71
Sulphur	0.45	1.34	0.90
Carbon	53.80	64.20	58.85
Hydrogen	3.15	5.36	4.48
Oxygen	15.57	29.13	22.20
Nitrogen	1.20	2.58	1.86
Heating power, B. t. u. per pound	8,979	11,510	10,212

TABLE XI.

Proximate Analyses of Texas Lignites—Alphabetically Arranged—Dry Basis. By S. H. Worrell.

Number and description of sample.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	Heating power, B. t. u., per lb.
40. Alba Lignite Co. Alba, Wood County	48.10	41.05	10.85	.80	10,220
59. Alba-Malakoff Lignite Co. Alba, Wood County	51.30	38.48	10.22	1.10	10,340
12. American Lignite Briquette Co. Big Lump, Milam County	55.70	30.09	14.31	.78	8,979
57. American Lignite Briquette Co. Big Lump, Milam County	49.21	39.53	11.26	.45	11,230
13. Bear Grass Coal Co. Jewett, Leon County	59.50	31.75	8.75	1.00	9,855
14. Bertetti Coal Co. Lytle,Medina County	55.00	31.91	13.09	1.33	10,510
16. Carr Wood & Coal Co. Lytle, Medina County	44.80	33.89	21.31	.97	9,344
41. Como Lignite Co. Como, Hopkins County	44.70	46.63	12.67	.64	10,600
17. Consumers Lignite Co. Hoyt, Wood County	52.14	38.22	9.64	.81	10,510
56. Consumers Lignite Co. Hoyt, Wood County	46.18	43.63	10.20	.68	10,840
18. Cookville Coal & Lumber Co. Mt. Pleasant, Titus County	58.60	30.61	10.76	1.05	9,782
36. Edgewood Coal & Fuel Co. Wills Point, Van Zandt County	56.18	37.20	6.62	.65	10,540
20. Houston County Coal & Mfg. Co. Crockett, Houston County	52.90	33.99	13.11	.80	10,120
21. Independence Mining Co. Phelan, Bastrop County	50.76	39.51	9.70	.90	10,226
22. Lone Star Lignite Mining Co. Como, Hopkins County	48.54	37.65	13.81	1.00	9,709
23. Melcher Coal & Clay Co. O'Quinn, Fayette County	49.28	32.90	17.82	1.34	9,709

Number and description of samples.	Volatile combustible matter.	Fixed carbon.	Ash.	Sulphur.	Heating power, B. t. u., per lb.
55. Rockdale Coal Co. Hicks, Lee County	51.20	38.78	10.02	.72	11,182
44. Rockdale Consolidated Coal Co. Rockdale, Milam County	43.38	41.43	15.19	.54	10,900
28. Rockdale Lignite Co. Rockdale, Milam County	47.60	41.31	11.09	.98	10,030
25. Rowlett & Wells. Rockdale, Milam County	49.00	44.00	7.00	.87	9,757
26. S. W. Fuel & Mfg. Co. Calvert, Robertson County	47.80	40.71	11.49	1.29	10,030
39. Texas Coal Co. Rockdale, Milam County	45.66	41.12	13.22	.80	10,410
29. Vogel & Lorenz. Rockdale, Milam County	50.52	39.20	10.28	1.20	9,855
Average	50.48	37.81	11.71	.90	10,212

The heat units in perfectly dry lignite compare fairly well with the heat units in Texas coals as they are mined, but the heat units in lignite as received at points of consumption are much lower than in dry lignite and much lower than they are in coal.

But this is the very point not covered in this Bulletin. We have no means of knowing, except in a few cases, how much moisture lignites contain as they are used. In comparing one lignite with another or lignite with coal for practical purposes it is necessary to know how much moisture they contain, for upon this depends, to a great extent, their value as fuel. The following table shows how great the differences in composition of lignites may be, according as they are considered with the moisture they contain or on a dry basis.

Average composition of Texas lignites with moisture and without moisture:

	With 25 per cent. of moisture.	Dry.
Volatile combustible matter	37.59	50.48
Fixed carbon	28.45	37.81
Ash	8.79	11.71
Sulphur	0.65	0.90
Heating power, B. t. u	7,661	10,212

The percentages for any intermediate amount of water may readily be calculated from the "dry" analysis. In comparing one lignite with another it is necessary to know how much water they contain, and what the composition would be if reduced to a dry basis.

But since it is impracticable to dry lignite before it is used, and since it is customary to use it as soon as possible after it is mined, the amount of water it contains, *as it is used,* is a very important consideration.

A case has recently been reported to us in which the heating power of a certain lignite, as received at the works, was 6,410 B. t. u., the moisture being 31.45 per cent. Theoretically a pound of this lignite should evaporate 6.63 pounds of water from and at 212 degrees Fahrenheit. The returns reported an actual evaporative power per pound of lignite of 3.25 pounds of water, or less than 50 per cent of the theoretical evaporative power.

While a part of this loss may have been due to an uneconomical installation, yet it does not appear that this would account for all of it. In dealing with lignite we have to remember that we have a fuel which may contain a full third of its weight of water, and that, aside from this, the volatile combustile matter, and, we suspect, the fixed carbon also, is different not only in amount, but in quality, from such substances in coal.

In producer practice and in ordinary steam installations these facts must be borne in mind, and both the producer and the fire-box grates and air inlets designed accordingly. There is a marked difference in lignites, and a producer, for instance, designed and built for a certain lignite, and which gives good results from it is not necessarily suited for all lignites. Nor is it merely a question of design and construction. The actual handling of the plant is, perhaps, of even greater importance. There are traveling grates that are used with a mixture of soft coal and lignite, and one operating successfully on lignite alone. Hand-firing, with a boiler similar in type to the half-Dutch oven has given, we understand, the best results from lignite.

In order to compare the heat units in lignite as actually determined with those obtained by calculation, we have prepared a table based on our recent analyses. The Goutal formula was used for the calculation based on proximate analyses and the DuLong formula for those based on ultimate analyses. The results are as follows:

Analysis No.	Heating Power, B. t. u., Dry.			Theoretical Evaporation in Pounds of Water from and at 212° F. per Pound of Lignite. Dry.
	Calculated.			
	From Proximate Analysis.	From Ultimate Analysis.	Determined.	
40	12,948	8,852	10,220	10.58
59	12,570	9,081	10,340	10.71
12	11,933	8,542	8,979	9.29
57	11,885	10,853	11,230	11.62
13	12,154	10,115	9,855	10.19
14	12,106	10,107	10,510	10.87
16	11,805	9,910	9,344	9.67
41	13,098	9,247	10,600	10.97
17	12,644	10,204	10,510	10.87
56	13,049	....	10,840	11.21
18	11,877	9,548	9,782	10.12
36	12,535	10,282	10,540	10.90
20	12,127	10,026	10,120	10.47
21	12,644	10,330	10,226	10.58
22	12,410	9,841	9,709	10.04
23	11,922	9,832	9,709	10.04
55	12,661	10,734	11,182	11.57
44	12,426	9,315	10,900	11.28
28	12,914	9,897	10,030	10.38
25	13,510	9,872	9,757	10.09
26	12,856	9,570	10,030	10.38
39	12,601	9,814	10,410	10.77
29	12,570	9,274	9,855	10.19
Average	12,489	9,784	10,212	10.56

An examination of this table shows that the Goutal formula applied to the calculation of heat units from the proximate analysis of lignites gives on the average, results that are 22.30 per cent higher than the heat units obtained by actual determination. It is, therefore, unreliable and cannot be used with a reasonable degree of accuracy.

The modified DuLong formula, applied to ultimate analyses of lignites gives, on the average, results that are 4.10 per cent lower than the determined heat units, and may be used for approximate results.

Applied to proximate analyses of coal, the Goutal formula gives results which, on the average, are 10.67 per cent too high, and the modified DuLong formula applied to ultimate analyses gives results which, on the average, are almost the same as those obtained in the calorimeter.

In the table giving the calculated heat units in Texas lignites we have included a calculation of the theoretical evaporation in pounds of water from and at 212 degrees Fahrenheit per pound of lignite, dry basis. The results vary from 9.29 to 11.62 pounds of water per pound of lignite, the general average being 10.56,

dry basis. In actual practice the efficiency of lignite as a fuel under steam boilers varies according to circumstances, and no rule of general application can be given.

Analyses of lignite made in the laboratory of the Bureau but not included in Table X, page 91.

Atascosa county, near Poteet, as received:

Analysis No.—	936	599	600
Moisture	24.00	25.00	34.82
Volatile combustible matter	36.07	18.20	19.73
Fixed carbon	32.97	43.80	34.62
Ash	6.96	13.00	10.83
	100.00	100.00	100.00
Sulphur	0.62	1.23	1.26
B. t. u., per pound	9,002	8,105	7,860

936. From Jos. A. Burger, San Antonio, 30 to 40 feet under cover; thickness of vein 4 to 5 feet.

599. From Poteet Sand & Coal Company, San Antonio.

600. The same.

Bastrop county: As received:

Analysis No.—	192	175
Moisture	24.50	10.00
Volatile combustible matter	38.02	47.00
Fixed carbon	30.54	24.09
Ash	6.94	18.91
	100.00	100.00
Sulphur	0.64	1.80
B. t. u., per pound	8,779	8,114

192. Independence Mining Company, Phelan.

175. Outcrop near Clopton Switch, 6 miles south of Elgin.

Bowie county: Sample from R. W. Rodgers, Texarkana. Analysis No. 38, as received:

	Per cent.
Moisture	13.68
Volatile combustible matter	48.59
Fixed carbon	26.27
Ash	11.46
	100.00
Sulphur	0.48
B. t. u., per pound	10,370

Brown county: Sample from D. F. Johnson, Brownwood. Analysis No. 695, as received. A typical form of lignite showing carbonized woody fiber, jet black in color:

	Per cent.
Moisture	18.04
Volatile combustible matter	44.91
Fixed carbon	35.82
Ash	1.23
	100.00
Sulphur	1.77
B. t. u., per pound	10,794

Fayette county: From mines of The Lower Strata Lignite Mining Company, Ledbetter; formerly known as The Big Four Mines, as received, percentages:

Analysis No.—	61	62	157	181	237
Moisture	19.82	27.80	33.50	39.00	38.50
Volatile combustible matter	36.45	38.31	33.45	35.69	34.77
Fixed carbon	28.23	13.08	18.23	21.05	19.99
Ash	15.50	20.21	14.82	4.28	8.74
	100.00	100.00	100.00	100.00	100.00
Sulphur	n. d.	n. d.	1.47	n. d.	n. d.

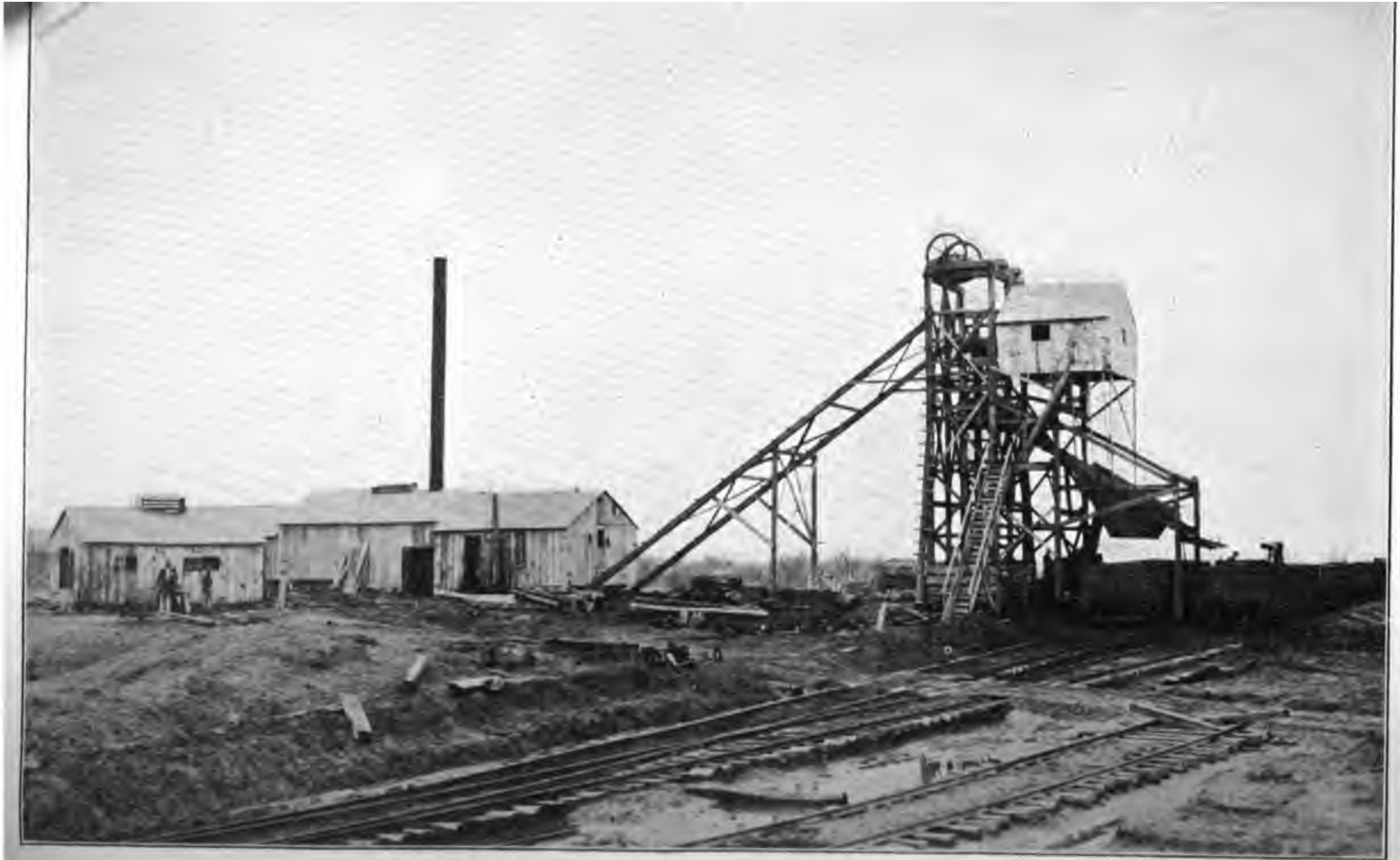
Nos. 61 and 237 are said to represent the 8-foot seam, 55 feet below the surface.

Nos. 62, 157 and 181 are said to represent the 7-foot seam, 95 feet below the surface.

Henderson county: Sample from W. Reid, Dallas Lignite Company, Dallas, of 12-foot vein, two and one-half miles from Stockard. Analysis No. 216.

	Per cent.
Moisture	25.00
Volatile combustible matter	36.81
Fixed carbon	29.89
Ash	8.30
	100.00
Sulphur	0.70
B. t. u., per pound	7,950

Assuming the same amount of moisture, Ledoux & Company, 99 John St., New York, gave analysis of lignite from the Dallas Lignite Company's mine at Tredlow, one and one-fourth miles east of Malakoff, as follows:



Alba-Malakoff Lignite Co., Mine No. 2, Malakoff, Henderson County.

	Per cent.
Moisture	25.00
Volatile combustible matter	34.47
Fixed carbon	33.25
Ash	7.28
	100.00

On the same basis, an analysis of this lignite, made by the Babcock & Wilcox Company, New York, gave:

	Per cent.
Moisture	25.00
Volatile combustible matter	33.59
Fixed carbon	33.39
Ash	8.02
	100.00

The vein at this locality is said to show 10 feet 6 inches of clean lignite without a parting.

A sample of lignite screenings received from the Malakoff mines of the Alba-Malakoff Lignite Company, May 15, 1913, had the following composition:

Analysis No. 751	Per cent.
Moisture	24.14
Volatile combustible matter	39.49
Fixed carbon	19.83
Ash	16.54
	100.00
Sulphur	1.08
B. t. u., per pound	7,578

Houston county: A sample of lignite screenings from the Houston County Coal & Manufacturing Company, Wooters, sent in by the Huntsville Light & Power Company, Huntsville, had the following composition:

Analysis No. 648,	Per cent.
Moisture	30.95
Volatile combustible matter	32.84
Fixed carbon	27.64
Ash	8.57
	100.00
Sulphur	1.43
B. t. u., per pound	7,855

Leon county: Bear Grass Coal Company, Jewett: as received:

Analysis No.—	551, Per cent.	307, Per cent.	933, Per cent.
Moisture	28.20	27.00	26.50
Volatile combustible matter	34.77	37.91	28.90
Fixed carbon	24.72	27.80	28.81
Ash	12.31	7.21	15.73
	100.00	100.00	100.00
Sulphur	1.02	0.44	1.11
B. t. u., per pound	7,805	7,308	6,528

Note.—Analysis No. 933 represents screenings through straight bars with ⅜-inch openings at bottom. About 20 per cent of the mine run passes the screen. Newby.

Mr. A. Bement, Chicago, made an analysis of Bear Grass lignite, March 11, 1909. In the samples as received, the moisture was 16.47 per cent, the ash was 11.24 per cent, and the B. t. u. per pound were 9,362.

Houston County Coal & Manufacturing Company, Evansville, Leon county:

Analysis No.—	342, Per cent.	927, Per cent.	928, Per cent.
Moisture	25.80	24.60	34.80
Volatile combustible matter	33.39	32.60	29.28
Fixed carbon	31.91	32.70	30.25
Ash	8.90	10.10	5.67
	100.00	100.00	100.00
Sulphur	1.04	0.62	0.55
B. t. u., per pound	8,146	7,760	7,619

Medina county: In a communication from the Carr Coal Company, San Antonio, May 26, 1913, it is stated that the following analysis more nearly represents the average of their Lytle lignite:

	Per cent.
Moisture	24.50
Volatile combustible matter	35.00
Fixed carbon	30.00
Ash	10.50
	100.00

Milam county: Two samples representing the lignite mined at Big Lump by the American Lignite Briquette Company. Analysis No. 420 represents the deep vein and was sent to us by the

Company, January 4, 1913. Analysis No. 833 represents a sample taken from the boiler room at Big Lump by Mr. E. L. Porch, Jr., July 11, 1913.

Analysis No.—	420, Per cent.	833, Per cent.
Moisture	24.20	32.00
Volatile combustible matter	36.28	29.77
Fixed carbon	30.62	29.20
Ash	8.90	9.03
	100.00	100.00
Sulphur	1.14	1.24
B. t. u., per pound	7,684	7,842

Lignite from the Texas Coal Company, Rockdale, sampled in University power house, May 9, 1913:

Analysis No.—	745, Per cent.
Moisture	29.60
Volatile combustible matter	31.50
Fixed carbon	30.24
Ash	8.66
	100.00
Sulphur	1.00
B. t. u., per pound	7,593

Robertson county: From near Bremond, July 5, 1913:

Analysis No.—	823, Per cent.
Moisture	31.00
Volatile combustible matter	34.02
Fixed carbon	27.88
Ash	7.10
	100.00
Sulphur	0.65
B. t. u., per pound	8,500

We have recently received some samples of lignite from near Wootan, Robertson county. The analyses of the samples and the descriptions are as follows:

Analyses Nos.	Samples as received:				
	953	954	955	956	957
Moisture	29.40	29.40	35.60	31.40	30.60
Volatile combustible matter	32.12	29.51	32.24	29.36	30.19
Fixed carbon	33.89	32.01	27.46	31.25	34.07
Ash	4.59	9.08	4.70	7.99	5.14
	100.00	100.00	100.00	100.00	100.00
Sulphur	0.73	0.91	0.88	0.88	0.86
B. t. u., per pound	8,110	7,438	8,219	8,386	8,938

953. On farm of Strumensky Son, 2½ miles northeast of Wootan, Robertson county, Texas. Thickness of seam, 6½ feet, in well 72 feet deep.

954. One and a quarter miles south southwest of farm of Strumensky Son, near Wootan, Robertson county. Thickness of seam, 6½ feet, in well 73 feet deep.

955. One-half mile north northwest of locality given in No. 954. Thickness of seam, 6 feet, in well 53 feet deep.

956. One-fourth of mile from locality given in No. 953. Thickness of seam, 8½ feet, in well 33½ feet deep.

957. From mines of Southwestern Fuel Company, Calvert, Robertson county. New mine. Sample taken 700 feet from shaft, north. Thickness of seam, 6½ feet. Depth below surface, 60 feet.

Smith county: In a communication from Mr. T. M. Coupland, Troup, December 9, 1912, we were given an analysis of a sample of lignite said to be from a depth of 800 to 900 feet, near Whitehouse, made by N. C. Hamner, Dallas. It was as follows:

	Per cent.
Moisture	14.45
Volatile combustible matter	38.82
Fixed carbon	35.18
Ash	11.55
	100.00
Sulphur	0.93

Upshur county:

Analysis No.—	54, Per cent.	148, Per cent.
Moisture	11.40	25.20
Volatile combustible matter	42.80	37.50
Fixed carbon	33.76	26.09
Ash	12.04	11.21
	100.00	100.00
Sulphur	0.88	1.20
B. t. u., per pound	....	7,650

No. 54. Sample from R. B. Nelson, Gilmer.

No. 148. Sample from R. E. Ezekiel, Kelsey, top of vein.

Walker county: From 10 to 15 miles north of Huntsville and south of Trinity river. Analysis by P. S. Tilson, Houston, of a sample from G. A. Wynne, Huntsville, February 8, 1909:

	Per cent.
Moisture	13.73
Volatile combustible matter	45.95
Fixed carbon	37.22
Ash	3.10
	100.00

Wood county: A sample of lignite screenings received from the Alba-Malakoff Lignite Company, Alba, Wood county, May 10, 1913, had the following composition, as received. Analysis No. 744.

	Per cent.
Moisture	25.80
Volatile combustible matter	36.55
Fixed carbon	24.67
Ash	12.98
	100.00
Sulphur	0.61
B. t. u., per pound	8,095

Consumers Lignite Company, Hoyt.

PERCENTAGES.

Analysis No.—	282	592	593	701	913	914	915	916
Moisture	24.10	33.46	33.14	32.79	25.85	27.51	26.54	24.95
Volatile combustible matter	36.48	31.51	30.81	29.51	35.58	33.42	30.85	32.21
Fixed carbon	31.92	27.44	27.39	28.94	31.30	28.12	32.71	32.06
Ash	7.50	7.59	8.66	8.76	7.27	10.95	9.90	10.78
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur	1.00	0.61	0.65	0.85	0.54	0.62	0.68	0.70
B. t. u., per pound	7,882	8,257	7,038	7,437	7,974	7,739	7,728	7,785

Note.—Analyses Nos. 282 and 913 are of lump; 593, 915 and 916 are dust; 914 is nut; 592 and 701 are screenings.

An analysis of this lignite made by Crossley Bros., Manchester, England (probably in 1909), gave the following results, in percentages:

	Per cent.
Moisture	24.50
Volatile combustible matter	31.30
Fixed carbon	38.00
Ash	6.20
	100.00
Nitrogen, dry	0.98

CHAPTER VII.

OTHER ANALYSES OF TEXAS LIGNITES.

In Bulletin No. 22, Bureau of Mines, Washington, 1913, there are given some analyses of Texas lignites made by the United States Geological Survey, and in the laboratory of that Bureau. A description of the samples and the analyses is as follows:

Houston county: Crockett, 11 miles south of Wooters Station, Room 17, north entry 3,890 feet from foot of shaft, 5 foot cut:

	Per cent.
Moisture	32.58
Volatile combustible matter	37.02
Fixed carbon	19.56
Ash	10.84
Sulphur	0.56
Same, main entry, 600 feet from shaft, 5.66 feet cut:	
Moisture	33.50
Volatile combustible matter	39.50
Fixed carbon	16.25
Ash	10.75
Sulphur	0.56
B. t. u., per pound	7,142
Same, over ½-inch bar screen:	
Moisture	34.70
Volatile combustible matter	33.23
Fixed carbon	21.87
Ash	11.20
Sulphur	0.79
B. t. u., per pound	7,056

Medina county: Lytle, Carr No. 3 mine, 350 feet, northeast entry No. 6, 51½ inches cut:

	Per cent.
Moisture	31.67
Volatile combustible matter	24.81
Fixed carbon	26.49
Ash	17.03
Sulphur	3.55
Same, 600 feet northwest; room at middle of northwest entry No. 5; 49¾ inches cut:	
Moisture	32.92
Volatile combustible matter	27.42
Fixed carbon	27.08
Ash	12.58
Sulphur	1.46
B. t. u., per pound	6,840

Milam county: Near Rockdale, Olsen mine, 400 feet east of shaft, 77 inch cut:

	Per cent.
Moisture	36.01
Volatile combustible matter	27.95
Fixed carbon	28.66
Ash	7.38
Sulphur	0.77
B. t. u., per pound	7,132
Same, 500 feet east of shaft, 79-inch cut:	
Moisture	35.56
Volatile combustible matter	28.91
Fixed carbon	27.49
Ash	8.04
Sulphur	0.75
B. t. u., per pound	.....
Same, lump, over ¾-inch screen:	
Moisture	31.06
Volatile combustible matter	27.67
Fixed carbon	33.39
Ash	7.88
Sulphur	0.99
B. t. u., per pound	7,870

Big Lump mine, 720 feet north of opening, entry No. 6, 7 foot cut, "big vein":

	Per cent.
Moisture	35.86
Volatile combustible matter	26.50
Fixed carbon	29.72
Ash	7.92
Sulphur	0.87
Same, 1,020 feet northwest entry No. 8; 82-inch cut:	
Moisture	35.30
Volatile combustible matter	26.22
Fixed carbon	29.58
Ash	8.90
Sulphur	0.76
B. t. u., per pound	6,898

Robertson county: Calvert, Calvert mine, room 4 of entry 1 south, 250 feet south of opening, upper 81¼ inch bed, 77-inch cut:

	Per cent.
Moisture	34.32
Volatile combustible matter	35.94
Fixed carbon	30.93
Ash	8.80
Sulphur	0.95
B. t. u., per pound	7,214
Same; room 8, off east entry north, 550 feet northeast of opening; 83½-inch bed, 78¾-inch cut:	
Moisture	33.50
Volatile combustible matter	26.06
Fixed carbon	30.38
Ash	10.06
Sulphur	0.97

Coming up the slope with a trip of loaded cars. Consumers Lignite Co., Hoyt, Wood County.

Wood county: Hoyt, No. 1 mine, south entry, 2,500 feet from mouth, 8¼ foot cut:

	Per cent.
Moisture	28.86
Volatile combustible matter	35.96
Fixed carbon	27.26
Ash	7.92
Sulphur	0.50
B. t. u., per pound	7,996
Same, No. 3 Mine, foot of air-shaft; 94-inch cut:	
Moisture	31.34
Volatile combustible matter	41.18
Fixed carbon	18.98
Ash	8.50
Sulphur	0.57
Same, run-of-mine:	
Moisture	33.71
Volatile combustible matter	29.25
Fixed carbon	29.76
Ash	7.28
Sulphur	0.53
B. t. u., per pound	7,348
Same, screened:	
Moisture	33.98
Volatile combustible matter	31.01
Fixed carbon	27.33
Ash	7.68
Sulphur	0.56
Same, 1,100 feet southeast of slope; 6½-foot cut:	
Moisture	36.80
Volatile combustible matter	28.86
Fixed carbon	28.09
Ash	6.25
Sulphur	0.53
B. t. u., per pound	7,101
Same, 400 feet northeast of slope; 8¼-foot cut:	
Moisture	34.87
Volatile combustible matter	29.80
Fixed carbon	27.69
Ash	7.64
Sulphur	0.50
Same, run-of-mine:	
Moisture	33.85
Volatile combustible matter	27.50
Fixed carbon	31.35
Ash	7.30
Sulphur	0.51
B. t. u., per pound	7,497

TABLE XIII.

Proximate Analyses of Texas Lignites, Compiled from E. T. Dumble's "Brown Coal and Lignite, 1892."

Analysis.	Moisture.	Volatile Combustible Matter.	Fixed Carbon.	Ash.	Sulphur.
A	8.35	41.28	42.73	6.40	1.24
B	12.40	36.37	37.77	13.60	not det'd
C	13.28	59.86	18.52	8.32	not det'd
D[1]	11.11	57.05	26.46	4.50	.87
E[1]	10.60	36.12	38.16	15.12	3.51
F	15.80	39.42	39.78	4.99	not det'd
G[2]	7.17	40.55	34.27	17.19	2.24
H[2]	20.29	32.67	26.58	17.50	3.11
I[3]	12.43	38.37	38.90	8.50	1.34
J[1]	6.25	54.05	33.47	6.27	.69
K[1]	16.56	45.10	32.89	5.49	not det'd
L[3]	8.41	38.41	28.65	23.38	.74
M	16.50	36.07	37.17	8.60	1.66
N	10.35	39.03	43.25	6.87	.50
O	12.00	42.00	32.00	13.00	not det'd
P	13.25	40.62	36.47	8.40	1.26
Q[3]	15.89	42.24	34.46	6.85	1.06
R[1]	6.50	46.64	28.02	17.72	2.22
S	20.80	52.08	22.67	3.97	.48
T[1]	10.17	39.52	36.60	12.80	.95
U[3]	16.45	40.24	35.89	8.95	1.17
V[4]	13.51	45.36	32.44	8.15	.88
W[1]	13.10	37.24	41.22	6.07	2.36
X[3]	10.11	37.37	24.39	27.59	1.15
Y	18.26	43.51	29.53	8.70	2.46
Z[4]	9.67	39.59	39.90	10.08	.76

[1]—Average of two analyses. [2]—Average of four analyses. [3]—Average of five analyses. [4]—Average of three analyses.

Key to analyses of lignites compiled from "Brown Coal and Lignite, Dumble," 1892:

A. Anderson county. From an outcrop on Caddo Creek, about seventeen miles northeast of Palestine: thickness, about two feet.

B. Angelina county.

C. Atascosa county, near Somerset: thickness, 5 feet 3 inches to 5 feet 6 inches.

D. Bowie county, near New Boston: thickness, 12 feet. One of the analyses shows 1.45 per cent of ash, with 76.41 per cent of volatile combustible matter and 10.62 per cent of fixed carbon.

E. Caldwell county. Burdett Wells.

F. Cass county. Stone Bluff.

G. Cherokee county. Bean's Creek, six miles south of Alto; near Jacksonville; McBee's school-house.

H. Fayette county. Manton Bluff: thickness, up to 15 feet. On O'Quinn Creek the lignite is of excellent quality and has a thickness up to 8 feet.

I. Harrison county. Robertson's Ferry and Rocky Ford, Sabine River; McCathern Creek: thickness, 2 to 6 feet.

J. Henderson county. C. M. Walters headright: thickness, up to 6 feet.

K. Hopkins county, near Sulphur Springs: thickness, up to 16 feet.

L. Houston county. Hyde's Bluff and Westmoreland Bluff, Trinity River; J. Bethel headright; Wallace headright, near Calthorp: thickness, 4 to 6 feet.

M. Lee county. Blue Branch: thickness, 6 feet.

N. Leon county, near Jewett: thickness up to 9 feet.

O. Limestone county. Head's Prairie.

P. Medina county. Lytle: thickness, 5 feet.

Q. Milam county. Rockdale: thickness, 4 to 6 feet.

R. Morris county. Pruit place: thickness, less than 2 feet.

S. Panola county. Mineral Springs Ridge, near Beckville: thickness, 4½ feet.

T. Rains county. Emory, and seven miles east.

U. Robertson county. Little Brazos; Calvert Bluff: thickness, 3 to 7 feet.

V. Rusk county. Iron Mountain; Graham's Lake, 12 miles west of Henderson: thickness, 3 to 6 feet.

W. San Augustine county. Sabine and Angelina Rivers: thickness, 6 to 15 feet.

X. Smith county. Southwest of Tyler, 8½ miles; south of Tyler, 6 miles; southeast of Tyler, 12 miles; west of Lindale, 3 miles: thickness, 3 feet and upwards.

Y. Shelby county. South of Timpson, 7 miles: thickness, 4 to 5 feet.

Z. Wood county. Alba and Mineola: thickness, 8 feet.

TABLE XIV.

Ultimate Analysis of Texas Brown Coals—From "Brown Coal and Lignite," Dumble, 1892.

County.	Moisture.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.	Sulphur.
Anderson	....	53.06	4.06	24.12	17.74	1.02
Bowie	10.67	59.84	3.10	26.97	9.10	1.00
Cherokee	....	66.67	3.81	22.08	5.83	1.64
Gregg	12.00	60.79	4.96	23.68	9.27	.88
Harrison	13.35	66.32	3.95	21.56	8.97	2.20
Houston	....	63.09	3.64	22.56	9.68	1.03
Lee	16.50	62.48	3.21	20.80	11.56	1.95
Leon	....	63.60	4.08	24.02	7.79	.55
Medina	13.25	60.92	2.57	25.34	9.70	1.47
Milam	....	60.93	4.12	22.27	11.36	1.32
Milam	17.75	62.50	5.45	20.84	7.54	.97
Milam	18.25	64.50	5.37	20.76	8.56	.81
Morris	8.55	59.87	4.70	24.35	8.66	2.42
Rains	....	57.04	4.01	24.48	13.35	1.11
Rains	....	59.32	2.80	20.27	16.63	.98
Robertson	....	58.16	4.46	13.11	12.77	1.50
Robertson	16.40	65.14	5.29	19.28	9.21	1.15
Rusk	16.63	58.93	4.20	22.14	10.09	4.64
San Augustine	....	61.12	3.32	24.53	7.75	3.39
Smith	9.83	57.40	3.60	23.31	14.74	.95
Webb (outcrop)	....	59.28	3.29	16.98	17.56	.89
Wood	10.85	56.33	4.29	24.13	14.39	.84
Average	13.67	60.98	4.01	22.16	11.01	1.48

The calculated heat units of some of the Texas lignites were also given by Mr. Dumble as follows:

	British thermal units, per pound. Dry.
From Medina county	11,320
From Milam county	11,169
From Milam county	11,278
From Robertson county	11,320

In the Second Annual Report, Texas Geological Survey, 1890, page 55, there are given some additional analyses of Texas lignites but they do not materially affect the results given above.

In a report on general mine conditions at Mines 5 and 6, Hoyt, made for the Consumers Lignite Company, May 8, 1913, by W. S. Hamnett, representative at Dallas for the Pittsburg Testing Laboratory, the following analyses were given:

Analyses Nos.—	Percentages as received.						
	1.	2.	3.	4.	5.	6.	7.
Moisture	27.03	26.00	28.45	27.27	28.28	27.67	27.48
Volatile combustible matter	33.41	32.41	33.15	34.44	31.61	32.02	32.24
Fixed carbon	30.25	29.63	30.56	28.69	27.16	31.06	33.01
Ash	9.31	11.96	7.84	9.60	12.95	9.25	7.27
Sulphur	0.79	0.85	0.73	0.79	0.83	0.71	0.69
B. t. u., per pound	7,813	7,538	7,706	7,809	7,246	7,710	8,004

1. Taken from the head of the main north entry, Mine No. 6.
2. Taken from Room No. 1, eighth cross from fourth east entry, Mine No. 6.
3. Taken from Room No. 10, fourth west entry, Mine No. 6.
4. Taken from Room No. 19, eighth east entry, Mine No. 6.
5. Taken from Room No. 4, second cross off sixth east entry, Mine No. 6.
6. Taken from the heading of third east entry, Mine No. 5.
7. Taken from Room No. 3, second east entry, Mine No. 5.

CHAPTER VIII.

RAW LIGNITE AS A FUEL UNDER STATIONARY BOILERS.

There are four principal methods of utilizing lignite (brown coal) in Europe, where the industry has long been established on a very large scale. These are as follows:

1. Raw coal, as a fuel under stationary boilers, etc.
2. Raw coal, as a fuel in gas producers.
3. Briquetting (1) the raw coal, or (2), the dry coal.
4. Dry distillation and recovery of by-products.

The use of powdered lignite as a fuel under boilers has been recommended and some establishments have done a considerable amount of work in this direction. A little lignite is also used for domestic fires. In Texas, a small amount of dust lignite is used in the manufacture of hollow brick tile for building purposes, as the lignite on burning out imparts a certain porosity to the product.

Of the four principal methods given above the first two are used in Texas. There is but little lignite used in Texas for household purposes or for use under locomotive boilers. We may now consider the various methods for utilizing lignite in the order given.

(1) *Raw Lignite as a Fuel under Stationary Boilers, etc.*

Irrespective of its use in gas producers, which will be considered later, and its use in household fires, the chief value of lignite is as fuel for generating steam, whether under stationary or in locomotive boilers. Under stationary boilers it may be used direct or in the form of pulverized fuel.

Of the 13,776,992 tons of lignite used in the United States between the years 1895 and 1912, inclusive, it is likely that 95 per cent, or more than 13,000,000 tons were used for making steam. For this purpose, the lignite is neither air-dried nor artificially dried, but is used, as mined, with such loss of its original moisture as may be due to air-drying between the mine and the consuming plant. Just what the loss of moisture may be, due to this cause, is not known with accuracy, for it is seldom the case that the moisture in the lignite as shipped and as received is determined. There are several factors that influence this matter, e. g., the amount of moisture originally present; the size of the lignite; the depth of the lignite bed in the car; the character of the car, whether a "gondola" or a box car; the atmospheric moisture and temperature; the length of time elapsing between shipment and receipt; the method of temporary storage, etc.

As a rule, lignite is not carried in stock, it is used as rapidly as possible after mining; but it has not infrequently happened that shipments have been delayed for 15 to 30 days in transit, even when the distance did not exceed 100 miles.

As soon as it is exposed to the air, lignite begins to lose moisture, and this may continue, in a hot and comparatively dry climate, until 50 per cent of the original moisture has been removed. During this drying the lignite breaks up into smaller and smaller pieces and more or less "fines" result. If the lignite is stored for considerable periods, spontaneous combustion may set in and the writer has been informed of a fire that began in this way, in a pile of Texas lignite. Spontaneous combustion may arise from the presence of excess of "fines," or dust, or finely divided pyrite (sulphide of iron) but does not seem to be much influenced by high volatile matter in the lignite. It is due to the oxidation of constituents in the lignite itself and when the heat generated by this oxidation is not lost through radiation or convection as rapidly as it is formed, the heating of the lignite may become so marked as to cause it to catch fire.

So far as now known there have been no systematic tests on our lignites to determine just what loss there may be on weathering; but in certain Illinois coals, which, however, do not correspond to lignites, a calorific loss of from 1 to 3 per cent, in a year, has been reported. In certain Wyoming coals, there was a loss of 2.50 per cent in the first three months and of 5.30 per cent in 2¾ years.[1]

It is probable that, up to a certain point, varying largely with the nature of the lignite itself, the loss of moisture increases the value of the lignite for fuel purposes, but just where this point may be is a matter to be settled for each case separately. On a carload of coal weighing 30 tons, and moved, we will say, 100 miles, in Texas, the freight is 60 cents a ton.

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[1] Comp. Bull. 38, Univ. Ill. Eng. Expt. Sta. 1909. Chemical Engineer, Vol. 12, July, 1910, and Tech. Paper No. 16, Bur. Mines, Washington, 1912.

With an average content of moisture of 31 per cent, there would be 9.30 tons of water in this car, on which freight has to be paid. The freight on 30 tons of lignite at 60 cents a ton is $18, of which $5.58 is paid on the water. This water is of no value in the lignite except as a sort of binder. When it is removed, the lignite breaks up; and the question is, whether the more solid lignite plus the water can be more economically used than the finer lignite minus the water. Up to a certain point it is probable that there would be a decided economy in removing a large proportion of this water, especially if this could be done on drying floors, or in revolving cylinders, heated by the waste heat from the boilers.

"The harmful effect of excessive moisture in lignite on steam boiler operation, is due to the fact that a large part of the heat held by the moisture is below the temperature of the water in the boiler, and hence is not available for making steam. This can be illustrated by a specific example.

"Suppose a boiler operates under a pressure corresponding to a steam temperature of 350 degrees Fahrenheit (about 135 pounds), absolute), that the temperature of the products of combustion is 2,000 degrees Fahrenheit and that the temperature of the atmosphere is 70 degrees Fahrenheit. Under these conditions, one pound of moisture in the products of combustion contains heat units below the temperature of the water in the boiler (and hence not available for absorption by the boiler) as follows: below the boiling point (212—70) 142 B. t. u.; latent heat of steam, 965 B. t. u.; superheating steam to 350 degrees Fahrenheit (350—212) x 0.48=66 B. t. u., making a total of 1,173 B. t. u.

"The heat units in this pound of moisture above the temperature of the water in the boiler (and hence available for absorption) are (2000—350)x 0.48=792 B. t. u. These figures show that the larger part of the heat in the moisture is not available for making steam. In fact, the moisture in lignite and the moisture formed by burning the hydrogen of lignite are equivalent to a small boiler placed in the furnace and making steam equal in weight to the moisture passing out of the furnace, thus absorbing that amount of heat before the main boiler gets a chance to absorb it."[1]

A temperature of 150 to 175 degrees F. would suffice for drying the lignite without seriously endangering the heat units through loss of volatile combustible matter, for there does not seem to be an appreciable loss of such matter under 220 degrees F.

If the moisture could be reduced to 20 per cent there would be a gain in heat units of 1,548, or 20 per cent; and if the moisture could be reduced to 15 per cent, the gain in heat units would be 1,939, or 26.30 per cent. Whether this gain in heat units would be more than counterbalanced by the cost of drying and the loss of fine lignite through the grate, is a question still to be settled. No general rule can now be stated, for lignites vary a good deal with respect to the proportion of "fines" resulting from drying. They do not all behave alike nor do they exhibit the same rapidity of drying under similar conditions. The more friable lignites, of comparatively loose texture, dry more rapidly than those of a more clay-like texture, although there may be no remarkable differences in chemical composition. The differences in friability among the lignites is especially noticeable on grinding, whether in a machine or by hand in a mortar. Some of them go to powder within a short while, while others are more or less spongy or smeary and go to powder only after long grinding.

The larger proportion of "fines" in the dried lignite, and the influence of these "fines" on the combustion and on the clinkering, has also to be considered. While the boiler setting, the character of the firebox, the position and arrangement of the fire arches and the combustion chamber, the rate of firing, the size of the fuel, the thickness of the fuel bed, the amount of air supplied and the rate and pressure at which it is supplied, are of great importance in all steaming operations on solid fuel, yet they are of particular moment when we consider lignite.

It is much to be regretted that in the State where there are the largest deposits of lignite and where the consumption of this fuel is greater by far than elsewhere in the country, there should have been so little systematic study of the economic use of such fuel.

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[1] D. T. Randall and Henry Kreisinger, Bull. No. 2, Bur. Mines, Washington, 1910.

Here and there, in Texas, there have been attempts to solve some of the more pressing problems in this connection, but there is no fuel testing station in the State where such investigations may be conducted by trained observers. Most of the information we have on the subject is derived from North Dakota, where the lignite area is only about one-half of that in Texas, where the production of this fuel is not half of the Texas production, and where the demand for cheap and effective fuel is certainly no greater than in Texas.

So far back as 1894 boiler tests on North Dakota lignite were made at Jamestown, North Dakota, under the care of Mr. Thomas Pettigrew, Chief Engineer for the Hospital for the Insane.[1]

Under natural draft, the water evaporated per pound of lignite actually consumed was 4.20 pounds, and 4.46 pounds per pound of combustible. The ash in the lignite was 5.93 per cent. The boiler was 6 feet in diameter and 16 feet long, with thirty 4½-inch flues. The grate surface was 4 feet 5 inches by 5 feet, or 22.8 square feet. The lignite burned per square foot of grate surface per hour was 18.72 pounds. The total amount of water evaporated at the temperature of the feed water (74 degrees F.) was 14,157 pounds. In comparison with Youghiogheny (Pennsylvania) bituminous coal, the water evaporation per pound of combustible was 4.46 : 7.10 pounds. The cost of the bituminous coal was $6.80, and of the lignite $2.80 a ton.

From another test of North Dakota lignite (same authority as above), with natural draft, made by the Missouri Valley Milling Company, Mandan, North Dakota, the following report was rendered:

Boiler Tests on North Dakota Lignite, at Mandan, N. D.

Duration of test	11 hours
Kind of furnace	Smith-White
Grate surface	30 sq. ft.
Width of air space in grate	¼ inch
Water heating surface	1,549 sq. ft.
Ratio of water heating surface to grate area	51 to 1
Average steam pressure, pounds per square inch	104
Average temperature of feed water entering boiler	175 deg. F.
Total lignite fed to furnace	12,221 pounds
Moisture in lignite	23 per cent.
Lignite consumed per sq. ft. of grate surface, per hour	37 pounds
Total cost of lignite	$9.77

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[1] F. A. Wilder, U. S. G. S., Water Supply and Irrigation Paper, No. 117, 1905.

Cost of lignite delivered at mill, per ton	$1.60
Total weight of water fed to boiler	56,350 pounds
Water evaporated per hour, from and at 212 deg. F	5,554 pounds
Horse-power developed	163
Cost of fuel for evaporating 1,000 pounds of water	17.34 cents
Average horse-power of engine	190
Cost of fuel per H.-P. hour	0.47 cent

The capacity of the mill was 450 barrels of flour per day and the cost of the fuel was 4.46 cents per barrel.

From a test made on North Dakota lignite at the Fargo-Edison Electric Light Plant, Fargo, N. D., in 1901, the following report was rendered:

Boiler Tests on North Dakota Lignite, at Fargo, N. D.

Natural Draft—

Duration of test	12 hours
Boilers used—Two 16 x 6 ft. tubular, one 220-h.-p. Heine water tube	
Total heating surface	4,823 sq. ft.
Total grate surface	88 sq. ft.
Average steam pressure, pounds per square inch	83
Average temperature of feed water, deg. F	140
Total weight of lignite fired	26,400 pounds
Cost of lignite per net ton at boilers	$2.60
Total cost of lignite	$34.32
Total weight of water apparently evaporated	97,500 pounds
Water evaporated per pound of lignite, from average pressure and temperature	3.70 pounds
Equivalent water evaporated from and at 212 deg. F	4.10 pounds
Lignite burned per square foot of grate surface, per hour	25 pounds
Cost of lignite to evaporate 1,000 pounds of water	35.2 cents
Moisture in lignite	30 per cent.
Ash in lignite	3.50 per cent.

Another natural draft test was made on North Dakota lignite at the North Dakota Agricultural College, in 1902. The report was as follows:

Duration of test	8.5 hours
Boilers used—Common fire tubular, with 62 flues 3 inches in diameter and 16 ft. long; diameter of shell, 60 inches.	
Total heating surface	962 sq. ft.
Total grate surface	24 sq. ft.
Total weight of lignite burned	3,907 pounds
Water apparently evaporated per pound of lignite burned	3.16 pounds
Equivalent water evaporated from and at 212 deg. F	3.38 pounds
Lignite burned per sq. ft. of grate surface, per hour	18.38 pounds
Moisture in lignite	36 per cent.
Ash in lignite	9.03 per cent.

Under forced draft, a test of North Dakota lignite was made at the University of North Dakota, in 1904. The boilers were fire tubular, with a diameter of shell of 54 inches. Each boiler contained 48 flues 16 feet long and 3½ inches in diameter, and had 841.76 square feet of heating surface. Fire brick arches were used in the furnace. The test lasted twelve and one-half hours. Per pound of fuel there were evaporated 4.30 pounds of water. After four days' air drying, the moisture in the lignite was 10 per cent and the ash 7.82 per cent.

Mr. Wilder remarks that with boiler and grate conditions about like those used in the test at the Asylum for the Insane, three Iowa coals, tested at Des Moines, gave a water evaporation, from and at 212 degrees F. of 5.44, 5.21 and 6.52 pounds per pound of fuel used, and that four standard Missouri coals gave 6.84, 6.27, 6.23 and 5.86 pounds, respectively. In comparing these coals with lignite, he allows for the lignite an evaporation of 4.20 pounds of water per pound of fuel and considers this conservative. Other instances of the fuel value of North Dakota lignite are given by Mr. Wilder as follows:

The 500-barrel milling plant of the Russell-Miller Milling Company, Jamestown: A single boiler 72 inches by 16 feet, with seventy-two 4-inch flues, a shaking grate, 36 square feet, with ½-inch air spaces, forced draft. The engine was a Corliss compound condensing rated at 165 horse power. The full power was maintained for twelve hours with 7,600 pounds of fuel, or one horse power from 3.73 pounds of the fuel per hour. The cost of the lignite at the mill was $2.45 a ton.

The Kenmare Roller Mill, Kenmare: Boiler 66 inches by 16 feet, with a grate of ⅜-inch spaces. There were used 161 pounds of lignite slack per hour, for 40 horse power, under 65 pounds steam pressure. The Minot Electric Light Company, Minot, had two boilers 54 inches by 16 feet, and maintained 50 horse power for ten hours with two tons of raw lignite. Natural draft was used and the engineer did the firing.

Automatic stokers and forced draft have given good results, but these have also been secured with natural draft and ordinary hand-firing.

One of the most complete tests of lignite as fuel under stationary boilers was conducted by D. T. Randall and Henry Kreisinger,[1] at Williston, North Dakota.

The boiler was one of six Stirling water-tube boilers installed for the Williston irrigation project of the United States Reclamation Service. It had three steam drums, one mud drum and three nests of tubes. The furnace was of the type which has been termed "semi-gas producer," with a deep-set grate and a narrowing of the space between the bridge-wall and the end of the prolonged fire-brick arch. The grate was 21 inches below the lower edge of the charging door. The air for combustion was pre-heated to 200 to 300 degrees F. and blown into the furnace under a water pressure of ½-inch to 1-inch. The grate was of the rocking-grate type, and had two rows of bars. Cold air was blown through a 2-inch pipe which supported each grate bar, with the hope that the formation of clinkers would be lessened or prevented.

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[1] **Bull. No. 2, Bur. of Mines, Washington, 1910.**

Inasmuch as considerable care was taken throughout this investigation, it has been thought best to speak of it at some length.

The principal dimensions of the furnace, boiler and grate were as follows:

Principal Dimensions of Furnace, Boiler and Grate Used in Tests of North Dakota Lignite, Williston, 1908.

Furnace:—	
Width in front	6.6 ft.
Width back of bridge wall	7.5 ft.
Length	8.0 ft.
Height	7.0 ft.
Roof of furnace:—	
Length (straight portion)	8.5 ft.
" at sides	15.8 ft.
" in middle	15.3 ft.
Height in rear, above bridge wall	23 in.
Number of openings[1]	16
Size of openings	2x4.5 in.
Width of partitions	2 in.
Bridge wall:—	
Width at base	5 ft.
Width on top	3 ft.
Height	40 in.
Number of openings[2]	6
Size of openings	5x2.5 in.
Side door:—	
Lower edge above grate	7.5 in.
Height	17 in.
Width	19 in.

Firing door:—	
Lower edge, above grate	21 in.
Height	14.75 in.
Width	19.75 in.
Chimney:—	
Height above grate	155 ft.
Diameter	54 in.
Boiler:—	
Builder's rating, H.-P	258
Water-heating surface	2,587 sq. ft.
Diam. of steam drums	42 in.
Length of steam drums	10.33 ft.
Diam. of mud drums	42 in.
Length of mud drums	8.33 ft.
Number of tubes	209
Diam. of tubes	3.25
Grate:—	
Width	6.6 ft.
Length	8.0 ft.
Width of grate bars	7.4 in.
Width of rib	0.44 in.
Width of air space	0.44 in.
Depth of air space	1.75 in.

[1]Note.—Openings in roof of furnace were 6.5 ft. from front of furnace

[2]Note.—Openings in bridge wall were 9 inches from front of bridge wall.

The average composition of the lignite used was as follows:

	Per cent.
Moisture	42.61
Volatile combustible matter	24.09
Fixed carbon	26.27
Ash	7.03
	100.00
Sulphur	1.04
Carbon	42.06
Hydrogen	3.04
Oxygen	14.80
Nitrogen	0.75
B. t. u., per pound	7,129

The total weight of fuel used, with moisture as above, was 431,326 pounds=215.66 net tons. The average amount of carbon left in the ash was 22.13 per cent, which, in the heat balance, represents an average loss of 1.93 per cent, due to incomplete combustion of the carbon. The equivalent amount of water evaporated from and at 212 degrees F. per pound of fuel, as fired, was on the average, 3.50 pounds, with an average developed horse power of 238.8. The over-all efficiency of the boiler and furnace was, on the average, 53.88 per cent, calculated from the chemical analysis of the coal and ash.

There was considerable trouble from clinkering and the removal of the clinkers was rendered difficult both by the deep setting of the grate and the inability to use tools through the side opening.

The chief conclusions reached by Messrs. Randall and Kreisinger, from the tests at Williston, are thus stated:

"The combination of boiler and furnace setting described gives good results with North Dakota lignite. Steam can be made with a fuel efficiency of 55 to 58 per cent of the heat in the coal, and no difficulty is experienced in obtaining the full capacity of the boiler.

"The results compare very favorably with the results obtained in the average plant using a good grade of bituminous coal when the heat available to the boiler is considered.

"Little, if any, advantage is gained by crushing the lignite by hand instead of in a power crusher.

"To reduce the moisture in the lignite by weathering seems to improve the economy, but these tests are not sufficient in number to determine definitely the condition of the fuel and the time required for weathering to insure the best results.

"The steam blower for the ash pit is inefficient, and there is no gain in supplying superheated steam to it. A considerable saving in steam and equally good results could probably be obtained by substituting for the steam blower a fan such as is commonly used for forced draft."

In tests at the Fort Worth Waterworks, Fort Worth, Texas, for the fuel contract of 1908-1909, lignite from the mines of the Bear Grass Coal Company, Jewett, Leon county, Texas, gave the following results:

Hours run, 66; pounds of lignite used, 102,448; gallons of water pumped, 8,877,050; gallons of water pumped per pound of coal, 95. The delivery cost of the lignite was $2.22 a ton, i. e., $1.50 at the mines and 72 cents freight. The cost of the fuel, per million gallons of water pumped, was $11.68.

This test was made in comparison with bituminous coal from Oklahoma, Arkansas and Texas. The cost of fuel, per million gallons of water pumped, was:

Name of company and kind of fuel.	Cost.
Southern Fuel Company (Oklahoma coal)	$ 9.74
Bear Grass (Texas lignite, mine run)	11.68
R. J. Clark (Oklahoma coal)	11.68
Dow Coal Company (Oklahoma coal)	12.86
Interstate Coal Co. (Arkansas coal)	14.16
Jenny Lind Coal Co. (Arkansas coal)	14.47
Rock Creek Coal Co., Texas	21.59

The results of some tests made at the Dallas Waterworks, Dallas, Texas, showed the following evaporation per pound of Oklahoma coal, with water temperature of 140 degrees F., 7.23, 7.30, 7.87, 6.42, 7.20, 5.32, and 4.91; an average of 6.61. Four Texas lignites were tested at the same time with the following results:

Location.	Water temperature.	
	140 deg. F.	212 deg. F.
Como, Hopkins county	3.565	4.05
Alba, Wood county	4.054	4.60
Hoyt, Wood county	3.981	4.51
Bear Grass, Leon county	6.667	7.308

Several years ago some fuel tests were made by Cypress Bros., Caldwell, Texas, with a 60 horse power shell boiler, each test being for eighty-four hours. Bituminous coal was charged off at $5.50 a ton, black jack (oak) wood at $5.50 a cord, fuel oil at 80 cents a barrel of 42 gallons, and Rockdale, Milam county, Texas, lignite at $1.75 a ton. The results showed that to produce one horsepower the relative costs were as follows:

Kind of fuel.	Cents.
For bituminous coal	1.33
For wood	0.90
For fuel oil	0.80
For lignite	0.70

In other words, it cost nearly twice as much per horse power to use bituminous coal as it cost to use lignite, one and a third times as much for wood as for lignite, and a little more for fuel oil than for lignite.

In a test conducted by J. P. Greenwood, M. E., Dallas, at the plant of the Columbia Manufacturing Company, Dallas, Texas, in May, 1912, with Hoyt screened lump lignite (Consumers Lignite Company) it was ascertained that the average evaporation per pound of lignite per hour was 4.44 pounds of water.

The equipment consisted of a battery of two O'Brien horizontal return tubular boilers, in brick settings, with a 4-inch air chamber wall vented to the outside. Each boiler was 72 inches in diameter and 22 feet long, with twenty-six 6-inch tubes. There was a furnace of 84 square feet of surface, common to the two boilers. The stack was 4 feet in diameter and 100 feet high, set on a twin up-take over the two boilers. In the up-take there was a bank of 2-inch pipes for increasing the temperature of the feed water. The grates were of special make, known as "Velvet," and were built for using lignite. They were 4 inches wide by 6 feet long, the width of the furnace being 14 feet. Each linear foot of grate surface had twenty-five round holes, ⅜-inch in diameter. The draft doors of the furnace were bricked up solid and in the center of each furnace there was an Argand steam blower, the steam entering at the center of a ring through eighteen holes, 1-32-inch in diameter.

As already stated, the fuel used was lump lignite from the mines of the Consumers Lignite Company, Hoyt, Wood county, Texas, screened over a ¾-inch screen and it showed 8,030 B. t. u. per pound.

There were six furnace doors, one fireman using each door alternately every few minutes. The average length of time the doors were open each hour was 24 per cent.

The fire was kept on the hill-and-valley system, on account of the large lumps of lignite, and Mr. Greenwood observes, in his report, that the lignite should have been broken into smaller lumps.

There was a ¾-inch steam pipe for each blower and the valves were kept wide open during the test. On account of the design of the blower equipment, almost no ash fell through the grates.

The light ash went over the bridge wall and was deposited in the combustion chamber. The clinkers, amounting to 4.50 per cent, were taken out through the furnace doors.

The heating surface of the two boilers was 2,354 square feet. While the builder's rating on the boilers was 294 horse power, there was actually developed 410 horse power. The combined efficiency of the furnace and boiler was 54 per cent. (Compare the efficiency of 53.88 per cent obtained by Messrs. Randall and Kreisinger on North Dakota lignite, with Stirling water tube boilers.)

The duration of the test was ten hours. During this time the following averages were obtained:

	Average.
Steam pressure	105 pounds
Air temperature	80 deg. F.
Up-take temperature	563 deg. F.
Feed-water temperature	192 deg. F.
Pounds of fuel per square foot of grate surface, per hour	36
Boiler, horse-power	410
Pounds of water evaporated per pound of fuel	4.44

The total amount of fuel used was 30,302 pounds and the total amount of water evaporated was 133,301 pounds. On a fuel basis, the cost of evaporating 1000 pounds of water was 16.9 cents, allowing that the coal cost $1.50 a ton, delivered. This represents a cost of $1.50 for evaporating 8,880 pounds of water. (Compare the cost of 17.34 cents for evaporating 1000 pounds of water with North Dakota lignite.)

In a private communication from the Consumers Lignite Company, July 3, 1912, it is stated that evaporative tests on nut and slack lignite, through a ¾-inch screen, showed 4.07 pounds of water per pound of lignite. The opinion is expressed, in that communication, that with an experienced fireman and under good conditions, the Hoyt lignite will show an evaporation of 5.50 pounds of water per pound of fuel. The average for Oklahoma coal appears to be 6.61 pounds.

In a test made at San Antonio, Texas, in 1910, by Charles V. Gambs, chief engineer of the Lone Star Brewing Company, on lignite supplied by the American Lignite Briquette Company, from its mines at Big Lump, Milam county, Texas, it was reported that the evaporation of water from and at 212 degrees F. per pound of the fuel was 5.50 pounds. Following are the items of this test:

Boiler Tests on Texas Lignite at San Antonio, Texas.

	Description.
Kind of lignite used	Big Lump lump
Duration of trial, hours	24
Kind of boilers used	Heine water-tube
Number of boilers used	3
Average steam pressure per gauge, pounds	100
Average temperature of feed water, degrees F	150
Average atmospheric temperature, degrees F	68
Total lignite consumed in 24 hours, pounds	64,944
Total water evaporated in 24 hours, pounds	324,720
Draft	Natural
Total water evaporated from and at 212 deg. F., pounds	358,490
Evaporation from and at 212 deg. F., per pound of fuel, in pounds	5.50
Horse-power developed, per hour	432.9
Temperature of escaping gases, deg. F	524.5

In tests made at the Temple Waterworks, Temple, Texas, in 1909, by Pat Bracken, superintendent, on five different kinds of Texas lignites, the results were as follows, each test being run for twenty-four hours:

Mine.	Lignite used, pounds.	Water pumped, gallons.	Cost, per 1,000 gallons.
Calvert	6,600 at $1.58	758,000	$0.0068
Bastrop	6,200 at 1.38	756,000	0.0056
Milano Coal Co	7,100 at 1.30	712,000	0.0064
Burnet Fuel Co	6,400 at 1.30	756,000	0.0055
Standard Lignite Co	7,600 at 1.30	900,000	0.0054

The fuel cost of pumping a million gallons of water, from this test, varied from $5.40 to $6.80. The number of gallons of water pumped, per pound of coal, varied from 100.30 to 121.90, with an average of 114.70.

Report by J. P. Greenwood, Dallas, Texas, December 6, 1911.

Central Texas Cotton Oil Company, Temple, Texas.

Duration of test, 10 hours.

Grate surface, 108 square feet.

Heating surface, 4,647 square feet.

Super-heating surface, not given.

Steam gauge, 120 pounds.

Draft, 0.5 inch.

Temperature of external air, 66.8 degrees Fahrenheit.

Temperature of fire room, 66.8 degrees Fahrenheit.

Temperature of steam, 349.6 degrees Fahrenheit.

Temperature of uptake, 463.5 degrees Fahrenheit.

Temperature of feed water, 198.3 degrees Fahrenheit.

Fuel.

Lignite consumed, 24,872 pounds.

Ash, 8 per cent.

Water.

Actually evaporated, 104,706 pounds.

Evaporated per pound of lignite, 4.20 pounds.

Evaporated per pound of combustible, not given.

Rate of Combustion.

Lignite per square foot of grate surface per hour, average 23.5 pounds.

Commercial Horse Power.

(34½ pounds water at 212 Fahrenheit) h. p., 320.7, average.

Rated H. P., 3 boilers, each 150.

Maximum h. p. developed, 341.5.

Minimum h. p. developed, 295.4.

Boilers.

Three, each 72 inches by 18 feet. Set in one steel casing with independent furnaces of the half-Dutch oven type. The steel breechings were side draft type and extended into a nipple on a 100-foot steel stack, 66 inches in diameter.

The fuel was Rockdale lignite, no analysis given.

Grate Surface.

Each boiler had 36 square feet, or 108 for the three. Grates were of herring bone type, with ⅜-inch air spaces.

The longitudinal space was ¾-inch.

The fuel average per hour was 2,487.2 pounds.

Water average per hour was 10,470.6 pounds.

The average evaporation per pound of fuel per hour was 4.2 pounds of water from and at 212 degrees Fahrenheit.

The average amount of carbonic acid for the 10 hours was 5.76 per cent.

Boiler Efficiency.	Per cent.
No. 1	75
No. 2	71
No. 3	70

After cleaning fires the highest evaporation was reached, 5.33

pounds when burning 19.5 pounds of fuel per square foot of grate surface.

The boiler feed pumps, 2, were 6 inches by 4 inches by 6 inches.

The heaters were of open type LXL Casey-Hedges and raised the temperature of the water to 198 degrees Fahrenheit.

Fuel, pounds.	Water, gallons.	Evaporation pounds.	Per square foot of grate.
2491	10,521	4.22	23.1
2372	10,521	4.43	22.0
2531	11,147	4.40	23.4
2516	10,521	4.18	23.3
3006	9,643	3.20	27.8 (cleaning fires)
2977	10,521	3.05	27.5 (cleaning fires)
2103	11,147	5.33	19.5
2645	10,521	3.97	24.5
2139	10,521	4.91	19.8
2092	9,643	4.60	19.4

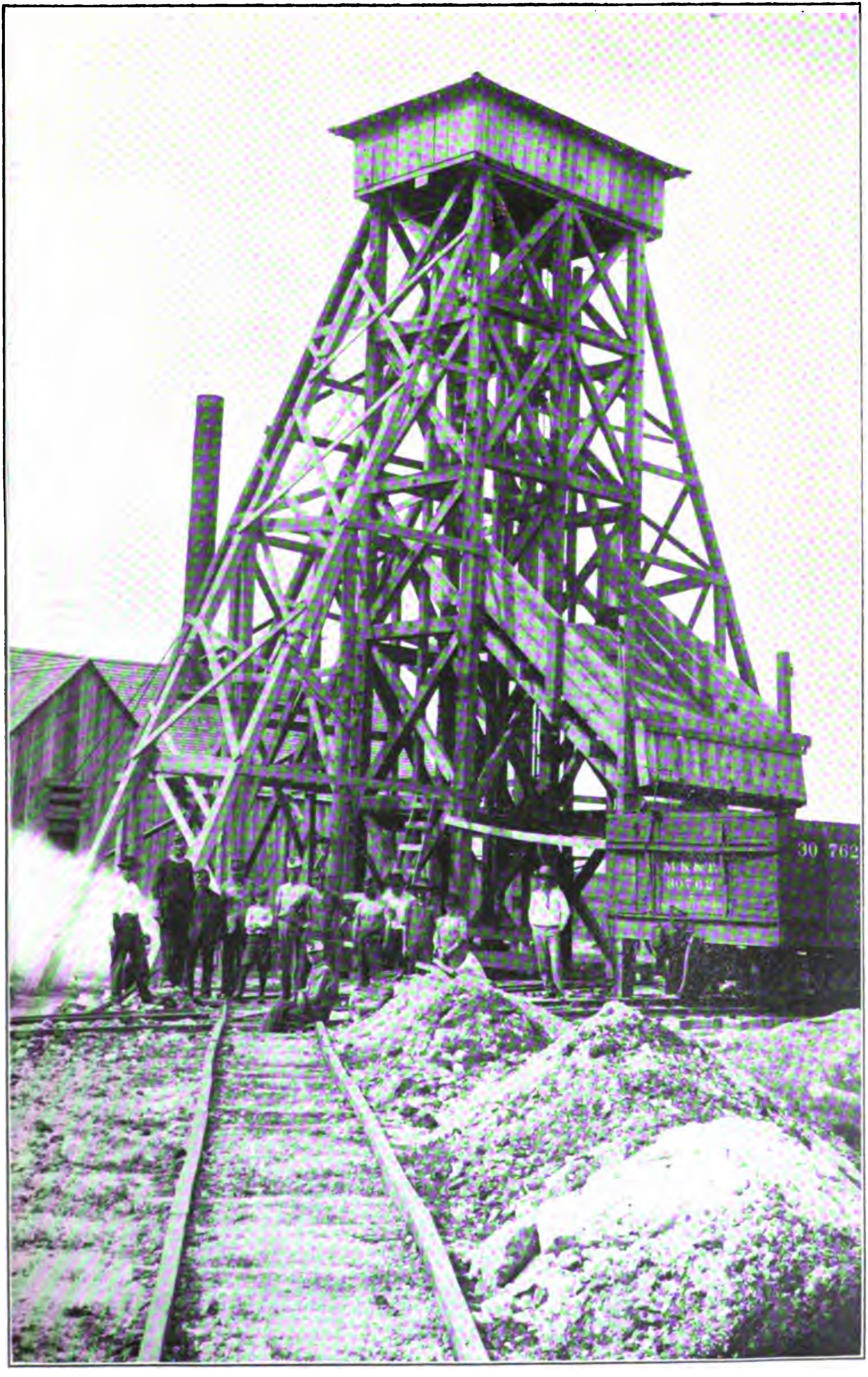
In July, 1913, with the permission of the American Lignite Briquette Company, Mr. E. L. Porch, Jr., made some observations for this Bureau at the Big Lump mines, near Rockdale, Milam county. His report is as follows:

"Description of the Power Plant"

"The boiler plant consists of two Casey-Hedges return tubular boilers (half-Dutch type setting). Both boilers are contained in the same setting and use a common 60-foot stack, the height above the grates being about 75 feet. The boilers are 18 feet long, 6 feet in diameter, and contain 86 3½-inch tubes, giving a heating surface of 1,420 square feet, for the tubes plus 170 square feet for the bottom of the boilers; or a total heating surface of 1,590 square feet for each boiler.

Each grate is 6 feet deep and 5½ feet wide, giving each boiler a grate surface of 33 square feet. The grate bars are the ordinary cast iron bars with V-shaped openings.

The steam pressure carried is 100 pounds, although it varied at times from 80 to 105 pounds. Each boiler is rated at 150 h. p., total 300 h. p. Run-of-mine lignite is used in the boilers, the pieces of lignite too large to fire being broken by hand on the boiler room floor. Some of this lignite used is quite wet, as it comes from the mines, also the boiler room (including the lignite) is sprinkled occasionally to lay the dust, this wet lignite being fired directly into the boilers. The boilers are fired approximately every



McKay Lignite Mining Co., Como, Hopkins County.

fifteen minutes, the bed on the grates being carried from 6 to 14 inches deep.

The water for the boilers is pumped from the mines before the day shift goes to work, there being no night shift. The exhaust steam from the compressor, the generator engine and the hoisting engine, goes through a (jet) condenser, no water being used in the condenser, however; and the very small part of the steam that condenses runs from the condenser through the feed water heater and is pumped up to the supply tank. The machines to which steam is supplied consists of:

One Ridgway engine (rated at 160 h. p.) driving a 100-k. w. (364 amperes, 250 volts) D. C. Thompson-Ryan Generator. The normal load on the generator was 75 amperes and the highest noted during the test was 330 amperes. This great variation of the load was caused by the starting and stopping of the electric locomotives that are used for the underground haulage, since they only operate a part of the time. An Ingersoll-Rand air compressor of about 35 h. p., a hoisting engine of about 60 h. p., and a saw-mill engine of about 15 h. p., total, about 270 h. p.

The results of the test do not show the boilers to be very rapid evaporators, but on Tuesday the plant was operating below its normal working capacity and on Friday conditions were still worse. For this reason Tuesday's and Friday's results were kept separate. Some smoke was noted during the test (as mentioned elsewhere), but the majority of the time the stack gave off no smoke. This seemed to be due to the type of setting, which gives an unusually large area of combustion, and possibly also to regularity in firing. The beds were not raked very often (3 to 4 times a day only) on account of the large amount of unburned lignite that would fall through the grate into the ash-pit.

Friday's Test

Duration of test—10:40 a. m.–4:05 p. m	5 hrs., 25 mins.
Lignite burned	6,834 lbs.
Lignite burned per sq. ft. of grate surface, per hour	19.1 lbs.
Water evaporated	19,199 lbs.
Water evaporated per hour	3,546 lbs.
Water evaporated per hour, per boiler	1,772 lbs.
Water evaporated per hour per pound of lignite, equals .336 gal., equals .336 x 8.355, equals	2.81 lbs.
Ashes drawn for the time specified, 1,200 lbs., equals, per boiler	600 lbs.

A very small amount of smoke was noted at 12:33 p. m., 1:30 p. m., 1:45 p. m., 2:00 p. m., 3:15 p. m. and 3:30 p. m.

An unusual amount of smoke for these boilers was noticed at 2:25 p. m., 2:45 p. m. and 3:00 p. m.

Tuesday's Test

Duration of test—9:40 a. m.–5:00 p. m	7 hrs., 20 mins.
Lignite burned	9,146 lbs.
Lignite burned per sq. ft. of grate surface, per hour	18.9 lbs.
Water evaporated	31,941 lbs.
Water evaporated per hour	4,352 lbs.
Water evaporated per hour, per boiler	2,176 lbs.
Water evaporated per pound of lignite, 0.418 gal., equals .418 x 8.355, equals	3.5 lbs.
Ashes drawn for the time specified, 1,492 lbs., equals, per boiler	746 lbs.

A very small amount of smoke was noted at 2:12, 2:25, 2:48, 4:07 and 4:27 p. m., which may have been due to a too vigorous raking of the fires, or to the boiler room having been sprinkled at about 2:00 p. m. The amount of ashes obtained in these tests is not exactly correct, because the mine pumps are run every morning from 3:00 a. m. to 7:00 a. m., and the amount of ash made during this time had to be estimated and deducted from the total amount drawn.

Under date of June 17, 1913, Mr. A. C. Köhler, Superintendent of the American Lignite Briquette Company, Big Lump, Milam county, wrote us as follows:

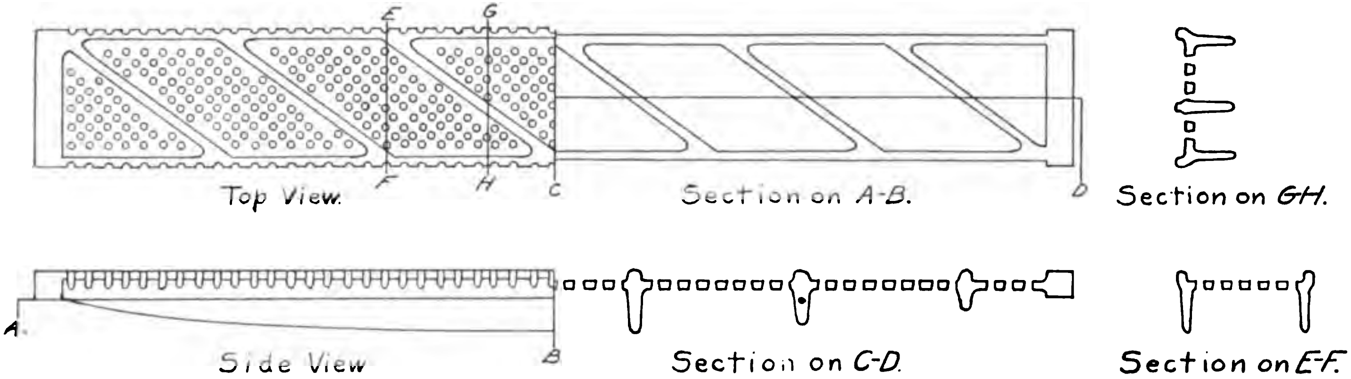
"We have two 150 h. p. boilers of the half-Dutch oven type, made by the Casey-Hedges Company, Chattanooga, Tennessee, at our Big Lump No. 5 mine, that have been in continuous operation for the past three years. While we have kept no exact costs on the operation of these boilers for any great length of time, we have made comparisons with the other types of boilers used here under the identical conditions and find that we can operate the semi-Dutch oven type far more economically, making a saving in fuel alone from 40 to 50 per cent. The first cost on the installation of these boilers was high as compared to the old style, but we feel that we have saved the difference several times over, in the fuel consumption.

As to the absence of smoke: the combustion is so thorough that they may be said to be smokeless. When properly fired, there is only a thin film of smoke and condensed vapor from the stack and this only for the moment when the fresh fuel is being fired. Altogether, this style of boiler and setting is the most satisfactory we have seen yet, especially when lignite is the fuel used."

Under date of June 10, 1913, Mr. M. F. Smith, Manager of the Georgetown Oil Mills, Georgetown, Texas, writes us as follows:

"We have been using the half-Dutch oven type of boiler, with steel setting, for about three years and we like it very much. We believe it to be more economical where a low grade of fuel, such as lignite, is used. With this type of oven, the fuel is completely burned and there is almost no smoke, unless a forced draft is used."

Mr. C. C. Roberts, Manager of the Ladonia Cotton Oil Company, Ladonia, Texas, writes us as follows, under date of June 10, 1913:



THE
VELVET GRATE BAR
for
Burning Lignite Coal

"Answering yours of the 7th instant; with reference to our experience with the Casey-Hedges Company half-Dutch oven type of boiler and their steel casing for same, beg to advise that we have had but little experience with same, using lignite as a fuel; however, the six or eight weeks that we used lignite, we found same to be very economical as against slack coal, and that our furnace gave entire satisfaction from point of combustion, no smoke being visible from stack only while furnace doors were open.

The reason we don't use lignite altogether is because our boiler capacity is rather limited, and when it becomes necessary to clean our fires, any low grade fuel gives us trouble, as we only have one unit and a limited amount of capacity.

We are well pleased with the boiler job the Casey-Hedges people gave us, as we have reduced our fuel cost almost 40 per cent since its installation, and find that we can use any grade of fuel to much better advantage than formerly."

Much other testimony could be adduced to show that, under proper conditions, lignite gives entire satisfaction as a fuel under stationary boilers and that it can be and is burned with almost no smoke. It may appear somewhat strange that there should remain in the minds of some people any doubt as to the advantage of this fuel, when we consider that Texas alone consumes a million tons a year and that the business is steadily growing.

The necessity of adapting the grate to the fuel led Mr. D. C. Earnest, Dallas, Texas, to take out patents on what is known as the "Velvet" grate. In a letter of August 31, 1913, Mr. Earnest, who is president of the Consumers Lignite Company, writes as follows:

"To show how the lignite business has developed, as far as this company is concerned, I will say that eight years ago it was the custom to load strictly mine-run. Among some operators there was a custom of forking the coal in the mines, but the miners got so expert with the forks that very little, if any, dust failed to get into the pit-cars. With the idea of producing a better grade of coal, we almost immediately installed screens, thinking that we could dispose of the screenings at some price. But we discovered that we could not even give this coal away, and the expense of merely throwing it away was, at times, from $250 to $300 a month. Since that time, the Velvet grates, in connection with the steam blowers, have enabled us to sell the screenings, or coal which comes through the ¾-inch screen, at from 50 to 60 cents a ton, f. o. b. mines. We have one customer, a brick manufacturer, who will take all the dust we can produce."

In response to our request, Mr. Earnest kindly sent the following description of his "Velvet" grate bar, which is illustrated.

"The 'Velvet' grate bar is especially adapted for burning lignite or any low grade fuel, either lump, mine-run, or slack.

The principal object of the grate is to secure a thorough distribution of air to the fuel on the grate, and the retention thereon, after raking the fire, of sufficient incandescent fuel to ignite a fresh supply of fuel.

The "Velvet" grate bar, in its general outline, is like the ordinary grate bar commonly used in boiler furnaces, being approximately rectangular in cross-section, and wider at top than bottom. It is provided on its top face with marginal ribs and transverse ribs or partitions, forming a plurality of individual fuel pockets adapted to retain fine fuel, and on its bottom face with recesses forming air pockets corresponding to the fuel pockets. These fuel pockets are about one-half to five-eighths of an inch deep. The fuel pockets are connected with the air pockets by ventilating holes, tapering, and largest at their lower ends, being about three-eighths of an inch in diameter at the top and fifty per cent larger at the bottom.

The tapering form of the ventilating holes tends to cause a discharge of the air in jets into the fuel.

In ordinary grates, especially where a forced or induced draft is used, there is a tendency of the air to rush through the weakest places in the fire. In the "Velvet" grate the individual air pockets underneath tend to prevent the air rushing past some of the ventilating holes and overcharging others. These air pockets form separate sources of supply to the separate groups of ventilating holes and cause an even distribution of the air to the fuel pockets in the top of the bar throughout the grate surface.

A steam blower is used with these grates; the blower may be put through the ash-pit wall, or through ash-pit door.

"Velvet" grates have been installed at more than 160 steam plants in Texas. Below are the names of a few:

Greenville Electric Light Plant, Greenville.
City Light and Water Plant, Terrell.
Grand Saline Salt Company, Grand Saline.
Tyler Cotton Oil Company, Tyler.
Tyler Electric Company, Tyler.
Smith County Compress Company, Tyler.
Houston Packing Company, Houston.
Fidelity Cotton Oil and Fertilizer Company, Houston.
Magnolia Petroleum Company, Corsicana.
Brazos Valley Cotton Mills, West.
Giddings Manufacturing Company, Giddings.
Union Iron Works, Houston.
Quanah Cotton Oil Company, Quanah.
Texas Power and Light Company, Palestine.
Henderson Cotton Oil & Ginning Company, Henderson.
Farmers and Ginners Cotton Oil Company, Sulphur Springs.
Fraser Brick Company, Ginger.
Bonham Ice Company, Bonham.
Planters Cotton Oil Company, Bonham.
Bonham Cotton Compress Company, Bonham.

Many fuel consumers have the erroneous idea that more boiler capacity is necessary when lignite coal is used as fuel. This is unquestionably untrue when "Velvet" grates are installed. These grates are installed on a guarantee of satisfaction, and when handled according to instructions, increased efficiency will be shown.

"Velvet" grates are covered by Patents Nos. 962805 and 972965, dated June 28, 1910, and October 18, 1910. Patent is owned, and installations are made, by D. C. Earnest, Dallas, Texas.

Reference has been made to the boiler setting for lignite manufactured and installed by the Casey-Hedges Company, Chattanooga, Tennessee. What is known as the half-Dutch oven steel setting has proved to be very satisfactory on Texas lignites and full particulars can be secured from that company. We can present here only a partial list of the installations in Texas, compiled to May 23, 1913.

Name of Company	Location.	Boilers.	
		Number.	Size, Inches—Feet
American Lignite Briquette Co	Big Lump	2	72 x 18
Central Texas Cotton Oil Co	Temple	3	72 x 18
Brownwood Ice & Fuel Co	Brownwood	2	72 x 18
Bruceville Cotton Oil Co	Bruceville	1	78 x 18
Carthage Ice & Electric Co	Carthage	2	72 x 18
G. F. Fitzhugh	Beaumont	3	72 x 18
Georgetown Oil Mill	Georgetown	1	78 x 20
Ladonia Cotton Oil Co	Ladonia	1	84 x 14
Lampasas Light & Water Co	Lampasas	1	60 x 16
Midlothian Oil & Gin Co	Midlothian	2	84 x 18
Paris Oil & Cotton Co	Paris	3	72 x 18

Total number of installations, 21. Of the standard casing installations, this company had, in Texas, 61 up to May 23, 1913.

Other large establishments are now concerned over the question of using lignite on stokers and the possibilities in this direction would appear to warrant all of the attention now being given to it.

In November, 1913, Mr. Jas. C. Kennedy, Brenham, Texas, read a paper on "Lignite Stokers" before the Southwestern Ice Manufacturers' Association, at Marlin. Mr. Kennedy has kindly placed this paper at our disposal, and we make the following extracts from it, as bearing particularly upon this subject.

Mr. Kennedy says:

"In handling the subject of lignite stokers, I cannot draw from my own experience, but must rely entirely upon facts and figures which I have obtained by correspondence with parties who have experimented with stokers or are using stokers for burning lignite. Just here, I will say that there have been and are yet a great many experimenters, but the users are very scarce.

"To get to a specific application of the stoker to lignite-burning, I will take the case of a stoker which was installed in our plant. The president of our company tells me that this stoker was the best money-maker that he had ever had offered him—on paper—and before it started to operate. The construction was the usual pattern of chain-grate stoker. The grate was built to cover the width of the furnace and was a unit without divisions longitudinally; but was arranged with rails and wheels so as to allow of removing it for inspection or repairs. A Dutch-oven construction extended from about 18 inches back of the front water by 5 feet 6 inches on the horizontal out in front of the boilers. The roof of the Dutch oven was lined with fire-tile and had an incline out and downward of about 15 degrees, from the horizontal. The top was one foot from the grate at the front end and two feet four and one-half inches at the back end.

"The top of the Dutch oven was called by the manufacturers the "ignition arch." Its business (according to the literature) was to get white hot and ignite the fresh lignite soon after it entered the furnace. The operation *was to be* this: The fire was to be started, as on any other grate, and allowed to heat up the surfaces, and especially the "ignition arch," at which time the stoker was set in operation and would take care of itself as long as you fed it coal. The burning fire on that part of the grate and of the arch under the tubes would radiate sufficient heat to maintain the arch at a white heat, and the arch would ignite the incoming lignite. The operation *was* this: The fire was started in the usual way; everything was heated up nicely, also the arch; then the stoker was placed in operation; but right here fiction stopped and actual events began to happen. When the fresh lignite was struck by the heat from the ignition arch, the large amount of moisture the fuel contained arose in a volume of steam and cooled the arch, and ignition was delayed until the fuel reached the furnace proper. It was also discovered that the fuel burned out before it reached the point where it was supposed to be ashes. This stoker was an absolute failure.

* * *

"In my endeavor to obtain information, I wrote to various concerns which are reported to have burned lignite with mechanical stokers successfully. Here is an extract from a letter:

" 'We have burned a little lignite on both of these grates with very good results, as compared with hand-firing. However, these grates were not installed at this plant for the purpose of burning lignite. They are strictly semi-anthracite.' Another paragraph reads: 'In burning lignite, a great deal depends on the arch. On this, if you go into it, you will probably have to do some experimenting with different constructions of arches.' I understand that this installation gave a great amount of trouble when it was first put in. Here is an extract from another letter from a man who had made a study of Texas lignites: 'We tried out lignite on a chain-grate stoker under a 200 h. p. B. & W. boiler, but found that it did not burn successfully because of the moisture in the fuel. The fire died out before the end of the grate was reached and, of course, the ignition was too slow.' "

"Here is one from Colorado: 'We have six B. & W. boilers, four of them 300 h. p., two 400 h. p. equipped with chain-grate stokers. Have had them in operation about three years. Our total expense for repairs on grates, gear, engine belts and brick-work, has been about $100 per year. We burn lignite altogether, except when there is labor trouble. We are saving from 20 per cent to 25 per cent of coal over good hand-firing. I am sending you analysis of the coal we burn, also some other information.' Following are the analysis and evaporation:

Kind of coal, Cruches mine run.	Per cent.
Volatile matter	33.23
Fixed carbon	35.25
Ash	7.79
Moisture	23.73
Calorific value; British thermal units	11,600

Water eqaporation from and at 212 deg. per lb., natural coal	5 lbs.
Water eqaporalion from and at 212 deg. per lb., dry coal	6.55 lbs.
Efficiency of boiler and furnace	56.9 per cent.
Draft suction uptake	0.57 inches of water.
Draft suction over ffre	0.24 inches of water.
Capacity of boiler	400 H. P.
Load developed	480 H. P.
Over rating	20 per cent.

" 'This was from an eight-hour test run before stokere were put in, stack temperature 600 to 700 degrees F.

" 'Another test run after stokers were installed, same coal used:

Water evaporated from and at 212° per pound, natural coal, pounds	6.14
Water evaporated from and at 212° per pound, dry coal, pounds	8.05
Efficiency of boiler and furnace, per cent	69.7
Draft suction uptake, inches of water	0.498
Draft suction over fire, inches of water	0.232
Capacity of boiler, 400 h. p.	
Horse-power developed, 502.	
Over rating, 28 per cent. Average C O 10 to 12.	
Stack temperatures between 500 and 600.	

" 'Both tests were run for eight hours, and in the case of the stoker we were not familiar at the time with the best method of firing. I believe the chain grate is the only stoker for lignite.'

"Here are two analyses of the lignite we are burning at Brenham, Texas:

	1. At the mine. Per cent.	2. Taken from in front of boilers as it was being fired. Per cent.
Moisture	20.82	13.74
Volatile combustible matter	43.31	38.10
Fixed carbon	29.87	38.30
Ash	6.00	9.86
Calorific value on wet basis, B. t. u	....	10,070
Calorific value on dry basis, B. t. u	....	11,670

Note.—Analysis No. 2 is more reliable as we had it made by a reputable, unbiased chemist. I am not so sure about No. 1.

"It has been impossible for us, on account of making alterations in our plant, to get exactly our evaporation factor, but, in the tests run last year, we had tests which ran as high as 5 pounds of wated to a pound of lignite as fired; our average being 4.5 pounds. Comparing the Colorado lignite and the lignite which we are using, it seems as if we would be better fixed to use a stoker than they are.

"The manufacturers of the type of stoker used with Colorado lignite claim to have more than sixty stokers burning lignite, in Colorado.

"What I have learned about stokers for lignite, as we find it in Texas, forces me to the conclusion that they are still in the process of development and, while I hear very often of what has been accomplished at this or that place, it has been impossible for me to secure authentic results of test.

"There are variables connected with lignite which make efficient stoking difficult.

"As set forth in another place, there is the moisture, the most variable of them all. If it leaves the mine in fair, dry weather, its moisture content will be lower when it reaches you; and, if the weather is damp or it is raining, you have more moisture. And good operation or, rather, good ignition and combustion by the stoker, requires some stability of moisture.

"The same mines have been known to produce lignite of variable chemical composition. I think this is true of all mines, although our lignite runs very uniformly.

"The requisites for successful mechanical stoking are the elimination of most of the moisture; the breaking up of the lumps to uniform sizes so as to obtain, as far as possible, the same grading; some mechanical means for avoiding surface coking; and the construction of ignition arch applicable to the particular fuel to be used. I have been informed that one of the large companies in this State is about to carry on some extensive experiments with a lignite stoker. We will all be glad, I am sure, to see success crown their efforts, as the fuel situation in this State is becoming a serious one.

"In conclusion, I wish to tell you that recently we are developing about 15 per cent over capacity with a boiler which formerly never exceeded 75 per cent of its capacity. The source of this increase consists of three elements: CO_2 Recorder; Rocking Grates and African muscle. The latter is a little hard to keep moving, but is the only stoker we have been able to rely on."

With respect to stokers using lignite: We have been furnished with the results of a test made on lignite from the mines of the Southwestern Fuel Company, Calvert, Robertson county, at Fort Worth, December 23, 1912. The stoker used was the Green Chain Grate, and the water evaporated per pound of lignite, under actual conditions, was 5.02 pounds, the horse-power developed having been 524, with a boiler efficiency of 73.4 per cent.

The details of this test are as follows:

BOILER TEST AT FORT WORTH.

BOILER.

Duration of test, 6 hours.
Plant, Swift & Company, No. 9.
Type, B. & W. Water Tube.
Diameter of shell, 42 inches.
Length of shell, 20 feet 4 inches.
Number of tubes, 224.
Diameter of tubes, 4 inches.
Heating surface, 4544 square feet.

FURNACE.

Type, Horizontal L Type GECO.
Depth, 11 feet.
Width, 8 feet.

Grate area, 88 sq. ft.
Kind of grate, Green Chain Grate.
Percentage of space, 15.
Ratio of heating to grate surface, 51.7:1.

COAL.

Kind of coal, Mine-run lignite.
Bought from Southwestern Fuel Co., general offices at Calvert, Robertson county.
Broken to egg size for firing.
Weight of coal as fired, 19,200 pounds.
Percentage of moisture in coal, 30.17.
Weight of dry coal consumed, 13,407 pounds.
Weight of ashes, 1441 pounds.
Weight of combustible consumed, 11,966 pounds.
Percentage of ashes to dry coal, 89.3.
Calorific value of fuel, dry, 10,669 B. t. u.

COAL PER HOUR.

Coal consumed, actual conditions, per hour, 3,200 pounds.
Dry coal consumed per hour, 2,235 pounds.
Combustible per hour, 1,995 pounds.
Dry coal, per sq. ft. grate surface, per hour, 25.4 pounds.
Dry coal, per sq. ft. heating surface, per hour, 49 pounds.

ANALYSIS OF COAL.	Per cent.
Fixed carbon	24.03
Volatile matter	38.32
Moisture	30.17
Ash	7.48

ANALYSIS OF ASH.

Moisture	0.28
Volatile combustible matter	16.01

WATER.

Total water evaporated, pounds	96,363
Equivalent water evap. from and at 212° F., pounds	108,408
Water evap. per hour, pounds	16,061

Equivalent water evap. per hour from and at 212° F., pounds	18,068
Factor of evaporation	1.125
Water evap. per sq. ft. heating surface, pounds	3.53
Water evap. per pound coal, actual conditions, pounds	5.02
Water evap. per pound coal, from and at 212° F., pounds	5.64
Water evap. per pound combustible, actual conditions, pounds	8.05
Quality of steam, per cent, dry	99.3

PRESSURES.

Steam pressure, pounds	146
Draft at uptake in inches water	0.77
Draft entering economizer over fire	0.24

TEMPERATURES.

Feed water, 136° F.
Escaping gases from boiler, 503° F.
Boiler room, 51° F.

HORSE POWER.

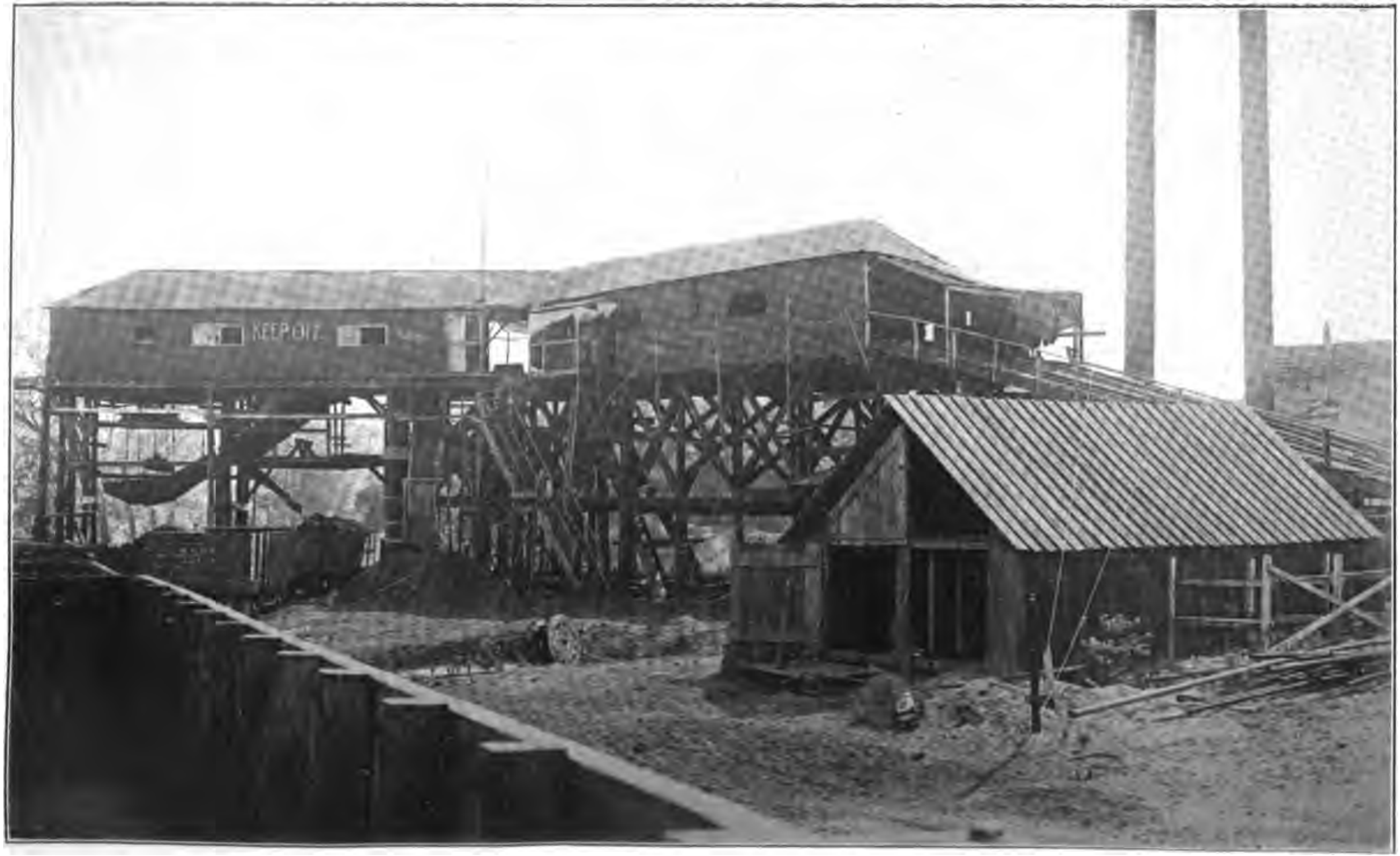
Rated horse-power of boiler	454
Horse-power developed from and at 212° F. (1 h. p. equiv. 34.5 pounds water)	524
Percentage above rated h. p.	15.4

ECONOMIC RESULTS.

Water evap. per pound coal, actual conditions, pounds	5.02
Equiv. evap. from and at 212° per pound coal, pounds	5.64
Equiv. evap. from and at 212° per pound dry coal, pounds	8.08
Equiv. evap. from and at 212° per pound comb., pounds	9.06

EFFICIENCY.

Efficiency of boiler (heat absorbed by boiler per pound of combustile, divided by heat value 1 pound comb.), per cent	74.8
Efficiency of boiler (heat absorbed by boiler per pound dry coal fired, divided by the heat value of 1 pound dry coal), per cent	73.4



Consumers Lignite Co., Hoyt, Wood County.

A large tonnage of lignite is now fired by hand and while this method unquestionably gives good satisfaction when proper care is bestowed on it, yet for large establishments, the use of an automatic stoker seems to be necessary. There are no insuperable obstacles to be overcome. The main points to consider are that in lignite we have a fuel that parts with its volatile combustible matter more quickly than ordinary bituminous coal does, and that the fixed carbon is not of a coking nature. This means that a large quantity of air must be supplied within a short time after the fuel begins to part with its volatile combustible matter, and supplied at the requisite points. The smoke must be prevented from forming, for it is difficult to handle it after it is once formed. The fixed carbon will take care of itself, if prevented from falling through the interstices of the grate; it is the volatile combustible matter that has to be cared for.

It does not appear that there are greater variations in the composition of lignites than in coals with which they are to compete, so that a stoker installation successful with one lignite should be capable of burning any other lignite, under comparable conditions. The preparation of lignite, according to size, has a direct bearing on the use of automatic stokers. In this connection we quote a letter received from the Consumers Lignite Company, Dallas, with reference to the practice at their mines at Hoyt, Wood county. "The cleaning of lignite slack, or its separation into nut and dust, was first suggested by the practice of the Fraser Brick Company, of Dallas, at its plant at Ginger, Rains county, of mixing a certain amount of lignite dust with the raw material for making fire tile. Their practice was to put the standard slack—all material through a ¾-inch bar screen—through a Williams crusher, set for ¼-inch. The possibility of making a separation of material of this size at the mines led to experiments at the mines of the Consumers Lignite Company, Hoyt, Wood county, Texas, in the summer of 1912, under the care of Mr. A. M. Hodges, assistant manager, and Mr. Drury McN. Phillips, mining engineer.

The original equipment provided for a two-size separation, graded as "lump" and "slack," the lump being all material over a ¾-inch bar screen 12 feet long and 5 feet wide set at an angle of about 35 degrees, and the slack being all material through this screen. These two grades of coal are delivered by gravity to gondola freight cars on two parallel tracks under the tipple, which is for slope hoisting. The amount of slack in mine-run coal varied from 18 to 23 per cent for the last year. Alterations in the existing installation were, of necessity, very limited and it was decided to provide a bin for the dust instead of loading it direct into the cars.

Preliminary experiments on a small scale showed that approximately 25 per cent of the slack was of suitable size and could be obtained through a properly slotted screen. This experimental screen was of ordinary corrugated iron, supported two inches above the floor of the slack pan, and extending two inches beyond the lower edge, across which was fitted a nozzle connected to the suction end of a gin fan. These experiments were so successful that a larger installation was planned, initial operation of which has shown a satisfactory extraction.

The screen at present used for making the separation into "nut" and "dust" is of No. 16 gauge galvanized sheet steel, in which have been cut slots ¼-inch wide by 4 inches long. The screen is 12 feet long and 5 feet, 9 inches wide, with a pitch of 35 degrees. The slots are arranged in parallel staggered rows 1¼ inches apart, with 2 inches of metal between slots in the same row. Thus there are 24 slots in a row and 50 rows, a total of 1,200 slots with an area of 1 square inch each, making the area of openings about 15 per cent of the total area.

Galvanized angle irons of 1½ inch are riveted along each side of the screen and through these angle irons are drilled six equally spaced ⅞-inch holes, corresponding to similar holes drilled in the sides of the slack pan 3½ inches above the floor. Through these holes and flush with the lower surface of the screen are passed ¾-inch stud bolts, secured by jamb nuts at each end. The lower edge of this screen extends 3 inches beyond the lower edge of the slack pan proper, thus affording ample clearance for the larger particles that slide on the screen without interfering with the finer material that passes through the slots and slides on the pan. Extending across this lower edge of the slack pan proper is a nozzle so designed as to give a uniform suction across its entire width and this nozzle is connected with an 11-inch sheet iron pipe running to the suction side of a 45-inch A. B. C. high speed fan. The distance from the mouth of the nozzle to the fan inlet is 17 feet, with a rise of 4 inches. The fan is belt-driven from a 30 horse-power Lansing engine, with a maximum speed of 1,800 r. p. m., but the necessary speed rarely exceeds 1,500 r. p. m. The distance from the fan outlet to the bin is 48 feet, with a rise of 7 feet, and the delivery pipe has a diameter of 11 inches. The bin is constructed to discharge into gondola cars through four spouts and has a capacity of 50 tons of dust.

The following analyses, made in the laboratory of the Bureau of Economic Geology, University of Texas, show the composition of the various sizes, the samples having been taken simultaneously at three different points. The lump and nut were taken from railroad cars being loaded at their respective shutes and the dust was collected at the mouth of the nozzle. The sample marked "dry dust" was taken from the bin and represents material after its passage through the fan and exposure to the air for several hours.

Analyses of Lignites from Consumers Lignite Co., Hoyt, Wood County, Texas.

	Per cent., as received.			
	Lump.	Nut.	Dust.	Dry Dust.
Moisture	25.85	27.51	26.54	24.95
Volatile combustible matter	35.58	33.42	30.85	32.21
Fixed carbon	31.30	28.12	32.71	32.06
Ash	7.27	10.95	9.90	10.78
	100.00	100.00	100.00	100.00
Sulphur	0.54	0.62	0.68	0.70
British thermal units per pound	7,974	7,739	7,728	7,785

	Per cent. on dry basis.			
	Lump.	Nut.	Dust.	Dry dust.
Volatile combustible matter	47.99	46.10	42.00	42.92
Fixed carbon	42.21	38.80	44.52	42.72
Ash	9.80	15.10	13.48	14.36
	100.00	100.00	100.00	100.00
Sulphur	0.73	0.85	0.92	0.95
British thermal units per pound	10,754	10,676	10,520	10,598

CHAPTER IX.

THE BRIQUETTING OF TEXAS LIGNITE.

Report of Professor E. J. Babcock, University of North Dakota, Grand Forks.

We do not propose to enter upon this subject in detail, for it would require a book to itself. All that is necessary at this time is to give the results which have been recently obtained from the briquetting of typical samples of Texas lignite in the Mining Experimental Sub-station of the University of North Dakota. We shall not discuss the briquetting of raw lignite, for we are of the opinion that this offers few, if any, commercial advantges over ordinary lignite.

Lignite briquettes should be made of carbonized material or material that has had most of the volatile combustible matter removed, whether in closed retorts or in bee-hive or recovery ovens.

We are aware of the experiments that have been made on the briquetting of raw lignite, but we do not consider the results obtained as of sufficient importance to warrant further discussion at this time. Furthermore, it is not necessary to discuss the briquetting of other lignites, for the heart of the matter lies in the results actually obtained from Texas lignites.

During the summer of 1912, we sent to the Mining Sub-station of the University of North Dakota, three separate shipments of 1,000 pounds each of the following lignites, contributed by the companies concerned:

Bear Grass Coal Company, Jewett, Leon county.

Consumers Lignite Company, Hoyt, Wood county.

Houston County Coal and Manufacturing Company, Evansville, Leon county.

We also shipped three barrels of Texas asphaltum (petroleum residue), contributed by The Texas Company, Houston, to be used as a binder for the briquettes.

The composition of the three lignites shipped was determined at the School of Mines of the University of North Dakota, as follows:

Bear Grass Coal Company, Jewett, Leon County.

	As rec'd, per cent.	Dry, per cent.
Moisture	9.30	....
Volatile combustible matter	42.40	46.35
Fixed carbon	39.51	43.18
Ash	8.79	10.47
	100.00	100.00
Sulphur	not det'd	not det'd
British thermal units per pound	10,263	11,315

Consumers Lignite Company, Hoyt, Wood County.

	As rec'd, per cent.	Dry, per cent.
Moisture	10.68	....
Volatile combustible matter	40.87	45.24
Fixed carbon	41.03	45.41
Ash	7.42	9.35
	100.00	100.00
Sulphur	not detr'd	not detr'd
British thermal units per pound	9,923	11,098

Houston County Coal and Manufacturing Company, Evansville, Leon County.

	As rec'd, per cent.	Dry, per cent.
Moisture	13.46	....
Volatile combustible matter	38.00	43.12
Fixed carbon	40.87	46.37
Ash	7.67	10.51
	100.00	100.00
Sulphur	not det'd	not det'd
British thermal units per pound	9,642	11,142

While these coals were in transit from Texas to North Dakota, they lost a large part of their original moisture.

The briquetting tests were under the immediate supervision of Professor E. J. Babcock, Dean of the College of Mining Engineering, University of North Dakota, whose excellent work on the North Dakota lignites needs no commendation here.

In abridging his thorough report we have omitted no essential facts bearing on this investigation.

Experimental Methods, Equipment, etc.

Report of Professor E. J. Babcock.

He says, under date of July 9, 1913:

"The tests given in this report were carried on both at the School of Mines and the Mining Experimental Sub-station of the University of North Dakota. The analyses and tests of the raw coal, the tests of the coal for the yield and quality of gas and carbonized residue, and the analyses of gas, residue and briquettes were all made at the experimental laboratories of the School of Mines at the University.

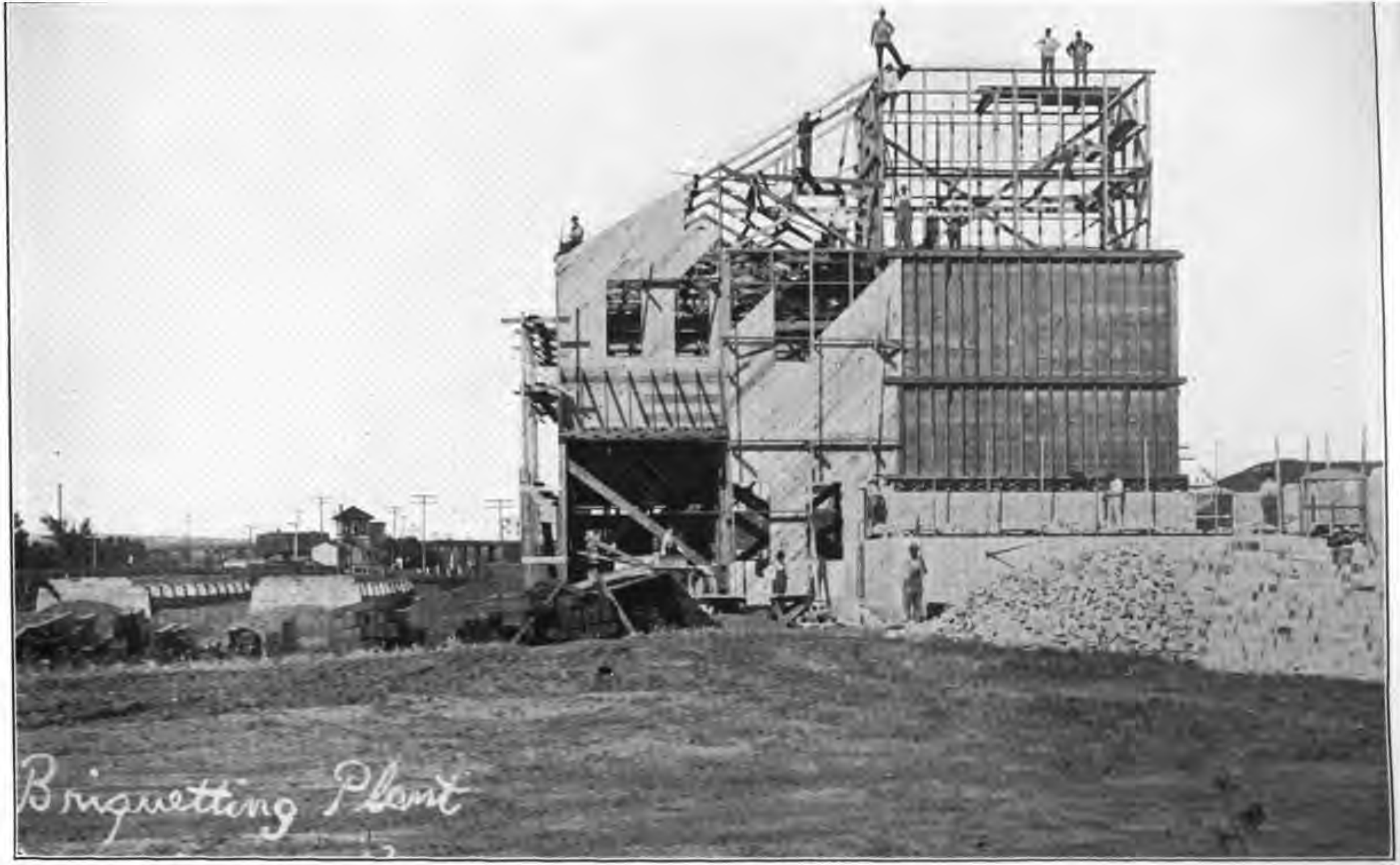
The carbonization of the residue for the production of briquettes and the manufacture of the briquettes from the various samples of coal and the various binding mixtures, was carried on at the Mining Experimental Sub-station under my supervision.

All of these tests were very thoroughly and carefully made with the purpose of approaching, as nearly as possible, conditions which could be secured in a commercial plant. The most serious difficulty in these tests was the lack of sufficient quantity of the different kinds of coal. For this reason, the gas tests were all made in our smaller plant at the School of Mines, but this has proven very satisfactory.

The small experimental gas plant in which this coal was tested for gas is very complete and of sufficient size to give accurate and reliable results and it approximates very closely the methods which might be actually used in the manufacture of gas from lignite on a commercial scale.

The retort is so arranged that pyrometer readings can be taken constantly during the carbonization, thus showing the yield at varying temperatures. The retort is connected by a riser to the hydraulic main. This hydraulic main is then connected with a secondary tar extractor of special design. From the extractor the gas passes to the condenser which removes water, any remaining tar and other solids or liquids. Beyond this is the scrubber provided with sprayer, coke trays, etc. From the scrubber, the gas passes to the purifier, having compartments for either lime or oxide of iron. An exit pipe leads from the purifier to the gas holder which is very carefully constructed and calibrated, and is provided with an accurately graduated scale reading the gas contents at any height to the one-hundredth of a cubic foot.

The holder is so constructed that the gas can be obtained under any pressure desired, and so compensated as to give a uniform pressure with any quantity of gas. It is also provided with thermometers, pressure gauges, etc. From this holder the gas is piped



Lignite Briquetting Plant under construction, [illegible] North Dakota

directly to the gas testing laboratory, where the chemical analyses and the calorific tests are made. The gas determinations were all corrected to normal temperature and barometric pressure.

Standard U. G. I. gas testing apparatus and government methods and a carefully standardized Sargent gas calorimeter were used. The gas and coke determinations were made in this experimental plant. (A more complete description of this plant may be found on page 30, bulletin entitled "Investigations of Lignite Coal Relative to the Production of Gas and Briquets," by E. J. Babcock, University of North Dakota, 1911.)

The carbonization of the lignite for briquettes was carried on at the Mining Experimental Sub-station and in our standard full size gas retort. The experimental gas plant at the Mining Sub-station consists of a bench of one retort, hydraulic main, condenser, exhauster, two scrubbers, purifier, meter, all of the full size used in commercial plants, and one gas holder, together with pressure gauges, pyrometers, temperature recording apparatus, etc.

The gas bench contains a standard retort 9 feet long, capable of carbonizing about 400 pounds of coal in four hours. This plant is complete and contains standard full size apparatus of the latest type. The temperature apparatus is very complete and conveniently arranged so that the temperature of the retort can be taken at any time by means of a high temperature pyrometer and the temperature and pressure of the gas can be taken in any part of the plant by means of a central temperature recording device and a central differential pressure gauge.

The Texas lignite carbonized in this plant was used for the production of briquettes. No determination of gas was made in the carbonization in the large plant as there was not sufficient quantity of the coal. Furthermore, the coal was not completely carbonized, as it was thought that with this particular lignite, and under your climatic conditions, it would not be necessary or desirable to attempt to drive off all of the volatile matter, so as to produce a briquette which could be used as a substitute for anthracite coal.

For this reason the Texas lignite used in making briquettes was only partially carbonized and in each case a different proportion of gas was extracted, leaving each residue entirely different in its proportion of fixed carbon and volatile matter. This method was pursued purposely because of the small quantity of coal available and the large number of tests desired. It was thought that by adopting this method, a large amount of data could be secured with the limited supply of coal. No analyses are given of the residues used in the briquettes. The relative amount of carbonization and some idea of the character of the residue in each case can be obtained by referring to the chemical analyses of the briquettes.

If complete carbonization is desired, the composition of the residue can be seen by referring to the gas and residue tests. Briquettes made from residue from which the gas has been nearly all extracted, will, of course, have a somewhat higher heat value and will give a denser and somewhat stronger and better product. But it was thought that in many cases in the Texas district it would not be desirable to extract all of the gas.

After the lignite was carbonized, it was removed from the retort and quenched by spraying with water. It was then conveyed to the grinding room where it passed through the pulverizer which reduced it to a size ranging from dust to fine shot. It was the intention to have about 75 per cent of it pass a 10-mesh, but retained on a 20 or 30-mesh screen. In running these small samples it was, however, impossible to put the samples through our larger crushers, elevators and mixers, since a considerable part of the samples would be lost.

For this reason it was necessary to grind these samples of lignite in a disc pulverizer and as the Texas lignite itself produces a good deal of fine material in crushing, and because of this type of grinder, the proportion of over fine material was too large, as will be seen by reference to the screening tests given in another part of this report. An excess of fine or coarse material will, in either case, lower the quality of the briquettes, especially with reference to strength and abrasive qualities.

After the residue was ground it was conveyed to a steam-jacketed mixer in which it was heated to the proper temperature and the binding material mixed with it. The binding material consisted of varying proportions of pitch and low grade flour, or ground screenings. The proportion of each is given in the description of the various briquette runs in another part of this report.

The proper proportions of water and steam were then introduced and the mixture thoroughly made, at a temperature of 170 to 180 degrees Fahrenheit. After the mixture was completed, it was cooled to the proper briquetting temperature and then passed through a rotary briquette press, making briquettes weighing from 2 to 2¼ ounces. This press has a capacity of about twenty tons per ten hours. The briquettes were then conveyed on a cooling belt to the storage bin and then were sacked ready for testing.

As has already been stated, we were unable to run these samples of coal completely through our large briquetting plant. It was necessary to use a small grinder and mixer, as already described. Had there been sufficient quantity of the Texas lignite (a carload) to have run through our complete plant, considerably better briquettes could, no doubt, have been produced, although the small sample lots which we made are very good, taking everything into consideration.

The experimental briquetting plant at the Mining Sub-station is a continuous one with a capacity of about twenty tons per ten hours. In this plant, as normally operated, the carbonized residue goes first to a disintegrator which breaks all lumps of residue to a quarter inch and finer. This is then conveyed to a set of rolls which reduce it to the proper size for briquetting. It is then elevated to a bin from which it passes through an automatic feeder which gives the correct proportion of residue to binding material.

At this point, an automatic feed delivers also the proper amount of ground screenings, or low grade flour, between 1 and 2 per cent generally being used. This mixture of ground residue is then delivered to a preheater and conveyer which conveys and mixes the dry material and at the same time brings it to about 100 degrees Fahrenheit and delivers it, at this temperature, into the mixer. At this point, the binding pitch is introduced through a rotary meter, giving the exact amount of pitch binder desired. The pitch used is generally what is known as 145 degrees melting point.

This pitch is melted in a steam heated tank from which it flows by gravity to the meter. It is then sprayed and blended with steam in the mixer. This mixer is steam-jacketed and so designed that it thoroughly mixes the binding material and the lignite residue, at the same time moving it forward and delivering it at exactly the proper speed for the briquetting press. On its way to the briquetting press, it is carefully tempered by a special device which cools the mixture to the proper temperature and which can be regulated to meet the changes in atmospheric temperature. The mixture then passes through the press and the briquettes are delivered to a cooling belt which conveys them to briquette storage bins.

This plant is complete and no hand work is done from the time the residue is delivered to the crusher. All of the machinery is very carefully timed so that every part operates at the proper speed and delivers exactly the right proportion of material. Considerable care and skill is required in the operation of the plant to keep the adjustment exactly right, but the plant has been so carefully worked out that it operates very uniformly and with comparatively little attention.

INVESTIGATIONS ON THE SEPARATE LIGNITES.

Bear Grass Coal Company, Jewett, Leon County.

The analysis of this lignite has already been given. The lignite, as received, yielded 11,450 cubic feet of unpurified gas per ton, the temperature of the retort ranging from 1,472 to 2,057 degrees Fahrenheit (800-1,125° C.). The composition of this gas was:

	Per cent.
Carbonic acid	14.1
Carbon monoxide	17.90
Illuminants	1.70
Oxygen	0.30
Hydrogen	44.60
Methane	16.60
Nitrogen	4.80
	100.00

British thermal units per cubic foot, 334.8.

The yield of residue was 52.34 per cent of the lignite as received and it had the following composition, dry:

	Per cent.
Volatile combustible matter	4.11
Fixed carbon	77.25
Ash	18.64
	100.00

British thermal units per pound, 12,820.

The yields of tar and ammoniacal liquor were not determined.

Briquette Tests.

A series of briquetting tests was made under varying conditions. The gas was not all driven off from the residue which was briquetted and on this account an entirely new series was obtained. The carbonization was carried on in a larger gas oven, only a portion of the gas being removed. The residue was crushed to the following sizes:

	Per cent.
Coarser than 10-mesh	0.38
Between 10 and 30-mesh	34.72
Between 30 and 50-mesh	20.66
Between 50 and 100-mesh	12.11
Finer than 100-mesh	32.13

By reference to this it will be seen that a large amount of the residue was crushed finer than 100 mesh. This was unintentional, as we aim to have very little as fine as 100 mesh. This residue seemed to crush to a fine powder much more readily than our North Dakota lignites and was ground finer than we intended. As a result, the briquettes are not as strong as they would be if there were not in them so much very fine material. It will, however, be difficult to get a large proportion of the right size without considerable fine dust from this residue, as the Texas lignite does not seem to give as hard a residue as that obtained from the North Dakota lignite.

Briquettes: This coal was used for the production of briquettes under a variety of modifications, some made of raw coal and some with the lignite residue, and each lot was made with varying proportion of binding materials. The purpose of this series of tests was to secure a wider range of briquette products so that a comparison of composition, heat value and general quality could be made, taking into account differences in cost of production, etc. The following series of briquettes was made from this coal:

Laboratory No. 2,887 A. These briquettes were made from slightly carbonized lignite residue. The carbonization was made in the regular standard size gas retort. The following mixture was used:

6 per cent. coal tar pitch, about 145 degrees melting point.

2 per cent. ground screenings, or low grade flour.

5 per cent. bituminous coal.
87 per cent. slightly carbonized lignite residue.

The composition of these briquettes is as follows:

Chemical Analysis Briquettes.

	As rec'd, per cent.	Dry, per cent.
Moisture	5.14	....
Volatile combustible matter	34.81	36.60
Fixed carbon	43.42	45.65
Ash	16.63	17.75
	100.00	100.00
British thermal units per pound	11,110	11,616

These briquettes have fairly good physical properties, although not as good as the other samples made from carbonized residue, probably for the reason that the residue from which these briquettes were made was only slightly carbonized. As has already been explained as in the case of the other briquettes, these briquettes are not as strong as those made from the harder North Dakota lignite residue, due largely to the fine powder obtained in crushing the carbonized residue. This can probably be considerably reduced in the operation of a plant by careful adjustment of the grinding machinery; but in this test the quantity was too small to admit of experimental changes in the grinding.

These briquettes, however, are quite satisfactory. They are nearly jet-black in color and have a very good surface. They are sufficiently strong to handle without great breakage and stand in the air without tendency to slack. Although but slightly carbonized, they hold their form well and burn well in the furnace.

These briquettes burn with a little more flame than those which are more fully carbonized, but after the combustion is well under way, the flame becomes very small and there is but little smoke. They burn quite freely, between the more fully carbonized and the raw lignite briquettes, but since a portion of the lighter gas has been taken out, they hold together well while burning. These briquettes are good for steaming coal under boilers and are excellent for furnaces, fire places and ranges; and while they are better than the raw lignite briquettes for use in self-feeding anthracite stoves, they are not as desirable for this purpose as the briquettes made from the completely carbonized residue. These briquettes, however, would probably give very good satisfaction.

Laboratory No. 2,887 B. These briquettes were made from raw lignite which had been dried, but from which the gas had not been removed. The following mixture was used:

11 per cent coal tar pitch, about 145 degrees melting point.
3 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
81 per cent raw lignite, dry.

Chemical Ananlysis Briquettes.

	As rec'd, per cent.	Dry, per cent.
Moisture	5.26	....
Volatile combustible matter	36.86	38.80
Fixed carbon	46.98	49.45
Ash	10.90	11.75
	100.00	100.00
British thermal units per pound	11,040	11,653

These briquettes are strong enough to stand a limited amount of handling but are not nearly as strong as they would be if they were made from carbonized lignite and therefore the breakage will be considerably greater. The color is nearly black. The shrinkage is comparatively small.

These briquettes stand very satisfactorily in the air, but as is usual with raw lignite briquettes, they crack considerably in the fire. due to the rapid production and escape of gas. However, they do not disintegrate and they stand up quite well in burning. As with all raw lignite briquettes, there is a considerable volume of flame, especially noticeable on fresh firing; and at this period there is also considerable smoke, due to the coal tar pitch used, but after the fire has gotten well started, the flame and the smoke are both largely reduced.

These briquettes burn very freely and too rapidly to be used as a substitute for anthracite. Furthermore, they contain too much gas to be used with entire satisfaction in self-feeding anthracite stoves. They can, however, be used in furnaces, ranges and under boilers, but will not hold the fire as well as briquettes made from carbonized lignite residue and will not stand handling as well. They have, however, a very good heating value.

Consumers Lignite Company, Hoyt, Wood County.

The analysis of this lignite has already been given. The lignite as received, yielded 9,970 cubic feet of unpurified gas per ton. The temperature of the retort ranged from 1,472 to 2,012 degrees Fahrenheit. (800-1,100° C.) The composition of this gas was:

	Per cent.
Carbonic acid	20.30
Carbon monoxide	15.30
Illuminants	1.30
Oxygen	0.40
Hydrogen	31.94
Methane	24.07
Nitrogen	6.69
British thermal units per cubic foot	335

The yield of residue was 54.69 per cent of the lignite as received, and it had the following composition, dry:

	Per cent.
Volatile combustible matter	11.37
Fixed carbon	73.53
Ash	15.10
British thermal units per pound	13,360

The yields of tar and ammoniacal liquor were not determined.

Briquette Tests: A series of briquetting tests was made under varying conditions, on material from which all of the gas had not been removed. The carbonization was carried on in a larger gas oven at the briquetting plant. The residue was crushed to the following sizes:

	Per cent.
Coarser than 10-mesh	1.48
Between 10 and 30-mesh	44.63
Between 30 and 50-mesh	16.52
Between 50 and 100-mesh	11.04
Finer than 100-mesh	26.34

As in the case of the preceding tests, the large amount of the residue was crushed finer than 100 mesh. This was unintentional, for the purpose was to have very little material as fine as 100 mesh. This residue seemed to crush to a fine powder much more readily than our North Dakota lignite, and the briquettes are not as strong as they would be if made from coarser material.

Laboratory No. 2,885 A. These briquettes were made from partially carbonized lignite residue, with the following mixture:

6 per cent coal tar pitch, about 145 degrees melting point.
2 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
87 per cent partly carbonized lignite residue.

The composition of these briquettes was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	2.50	....
Volatile combustible matter	22.44	23.00
Fixed carbon	58.53	60.00
Ash	16.53	17.00
	100.00	100.00
British thermal units per pound	11,640	11,938

These briquettes have fairly good physical qualities, and will probably give satisfaction. Their color is nearly jet black. They have a reasonably good surface and are fairly dense. They are sufficiently strong to handle without an excessive amount of breakage. They stand in the air without any tendency to slack. They burn with a small amount of flame which is noticeable mostly at the beginning of the fire, but after combustion is well started, they burn with but little flame and smoke. They burn freely and hold together well while burning. They can be used in an anthracite self-feeding stove and in furnaces, fire places, or ranges. They can also be used for steam purposes, although with a little more volatile matter they would give a longer flame. For general fuel purposes, these briquettes would give very satisfactory results.

Laboratory No. 2,885 B. These briquettes were made from partly carbonized lignite residue. The carbonization was made in a standard gas retort. The briquettes were made with the following mixture:

10 per cent coal tar pitch, about 145 degrees melting point.
2 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
83 per cent partly carbonized lignite residue.

The composition of these briquettes was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	2.48	....
Volatile combustible matter	32.64	33.45
Fixed carbon	51.81	53.10
Ash	13.07	13.45
	100.00	100.00
British thermal units per pound	12,627	12,920

These briquettes have fairly good physical properties, and would probably give satisfaction, and the same remarks made under 2,885 A are applicable here. They seem to be somewhat stronger than briquettes No. 2885 A and would doubtless stand handling somewhat better.

Laboratory No. 2,885 C. These briquettes were made from raw lignite, from which most of the water was removed, but without the removal of the gas. The following mixture was used:

10 per cent coal tar pitch, about 145 degrees melting point.
2 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
83 per cent raw lignite, dry.

The composition of these briquettes was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	5.62	....
Volatile combustible matter	43.65	46.10
Fixed carbon	41.28	43.60
Ash	9.45	10.30
	100.00	100.00
British thermal units per pound	12,070	12,788

These briquettes are probably strong enough to stand handling to a limited degree, but they are not nearly as strong nor as satisfactory as the briquettes made from the carbonized lignite. The waste in breakage where there is much handling would be considerable. These briquettes stand very satisfactorily in the air, but in the fire they crack considerably, due to the rapid production and escape of gas. They do not, however, disintegrate, but will stand much poking while burning. There is a large volume of flame, especially noticeable on fresh firing, and in this respect they are very similar to dry lignite. There is also a considerable amount of smoke at this period, due to the coal tar pitch used, but after the fire is well started the flame is somewhat reduced, and the smoke largely disappears. These briquettes burn very freely, and too rapidly to be satisfactory as a substitute for anthracite; and they also contain too much gas to be used in a self-feeding anthracite stove. They could, however, be used in furnaces, ranges, and under boilers, but they do not hold the fire as well as the briquettes made from the carbonized lignite residue. They could not be considered very satisfactory for general commercial use.

Laboratory No. 2,885 D. These briquettes were made from raw lignite, from which most of the water had been removed, but without the removal of the gas, and in this respect they were similar to briquettes 2,885 C. The following mixture was used:

15 per cent Texas petroleum residue.
1 per cent ground screening, or low grade flour.
5 per cent bituminous coal.
79 per cent raw lignite, dry.

Their composition was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	5.63	....
Volatile combustible matter	40.80	43.10
Fixed carbon	44.59	47.10
Ash	8.98	9.80
	100.00	100.00
British thermal units per pound	11,990	12,705

These briquettes are very good physically. They are quite dense, and as soon as they are dry from the press, they stand handling very well, and I think that the breakage in any reasonable handling would be comparatively small. The color is almost coal black. The surface is very smooth and satisfactory and they stand exposure to the air without any signs of change. They crack in the fire considerably, but do not disintegrate, although they do not stand much poking while burning.

It will be noticed that we reduced the percentage of flour and an additional amount of asphalt was used, and it is probable that 15 per cent of the asphalt could be used without making the briquettes too costly. There is a large volume of flame, especially noticeable on fresh firing, but not much smoke. These briquettes, with 15 per cent petroleum residue are much better than the briquettes made from raw lignite with either 10 or 12 per cent of coal tar pitch. The Texas petroleum residue seems to be an excellent binding material. It evidently requires a little longer to gain its strength than coal tar pitch does, and it is not quite as hard. It seems to be much more elastic, and therefore the briquettes will probably stand handling fully as well as the briquettes mades of coal tar pitch. It also has the advantage of giving much less black smoke. These briquettes burn very freely, and probably too rapidly to be used as a substitute for anthracite, and they also contain too much gas to be used to good advantage in a self-feeding anthracite stove. They could, however, be used for the same purposes as briquettes No. 2,885 C.

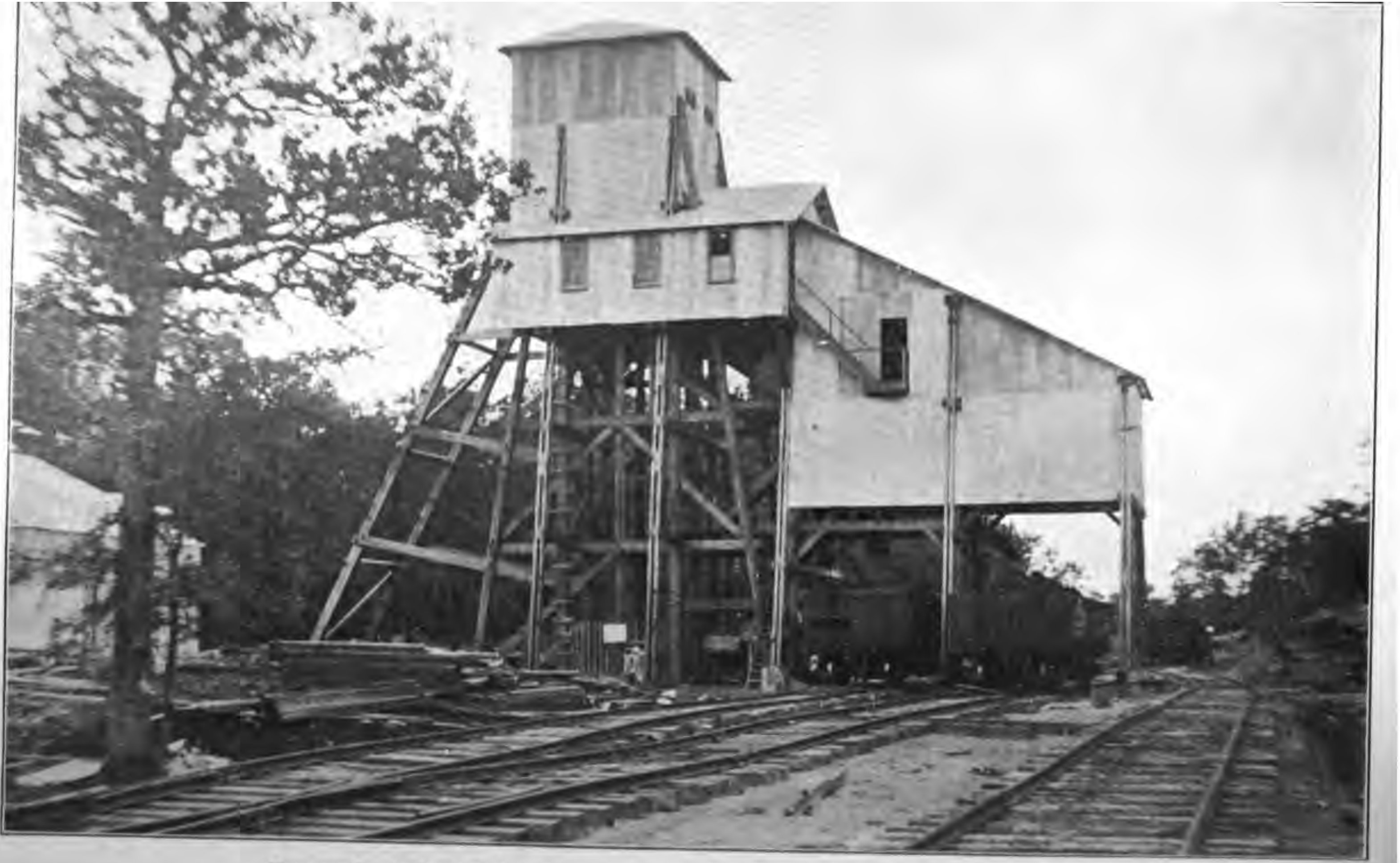
Laboratory No. 2,885 E. These briquettes were made from raw lignite from which most of the water had been removed, but without the removal of the gas. The following mixture was used:

12 per cent coal tar pitch, about 145 degrees melting point.
3 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
80 per cent raw lignite, dry.

Their composition was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	4.17	....
Volatile combustible matter	41.28	43.00
Fixed carbon	45.89	47.80
Ash	8.66	9.20
	100.00	100.00
British thermal units per pound	11,180	11,666

These briquettes are very similar to No. 2,885 C. They seem to be a little stronger and will probably stand handling, to a limited degree, a little better, but they are not as satisfactory as No. 2,885 D, made with 15 per cent of Texas petroleum residue. The color is a brownish black. These briquettes are considerably smaller than those made from carbonized residue. The shrinkage is greater on drying than in the briquettes made from carbonized residue, and also greater than in the raw lignite briquettes in which 15 per cent of petroleum residue was used. They stand very satisfactorily in the air, but in the fire they crack considerably. They will not



Houston County Coal & Manufacturing Co. Tipple at Evansville, Leon County. Lignite.

stand much poking while burning. There is a large volume of flame and considerable smoke.

It will be noticed that in this mixture a large per cent of pitch and flour renders the binder rather expensive, especially when applied to raw lignite. These raw lignite briquettes cannot be considered commercially satisfactory.

Houston County Coal and Manufacturing Company, Evansville, Leon County.

The analysis of the lignite has already been given. The lignite as received yielded 10,250 cubic feet of unpurified gas per ton, the temperature of the retort ranging from 1,742 to 2,012 degrees Fahrenheit. (950-1,100° C.). The composition of this gas was:

	Per cent.
Carbonic acid	14.90
Carbon monoxide	17.60
Illuminants	1.60
Oxygen	0.60
Hydrogen	41.25
Methane	15.87
Nitrogen	8.18
British thermal units per cubic foot	335.20

The yield of residue was 49.3 per cent of the lignite as received, and it had the following composition, dry:

	Per cent.
Volatile combustible matter	4.79
Fixed carbon	77.04
Ash	18.17
	100.00
British thermal units per pound	12,327

The yield of tar and ammonia was not determined.

A series of briquetting tests was made on material from which not all of the gas had been removed. The residue was crushed to the following sizes:

	Per cent.
Coarser than 10-mesh	0.24
Between 10 and 30-mesh	22.46
Between 30 and 50-mesh	13.93
Between 50 and 100-mesh	15.57
Finer than 100-mesh	47.80

The same remarks in regard to sizing apply here as in the other cases.

Laboratory No. 2,886 A. These briquettes were made from partly carbonized lignite residue, the carbonization having been made in the regular standard size gas retort. The following mixture was used:

8 per cent coal tar pitch, about 145 degrees melting point.
2 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
85 per cent partly carbonized lignite residue.

The composition of the briquettes was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	7.00	....
Volatile combustible matter	18.00	19.26
Fixed carbon	57.46	61.48
Ash	17.54	19.26
	100.00	100.00
British thermal units per pound	11,190	12,032

These briquettes have good physical properties and would give good satisfaction. Their color is nearly jet black, they have good surface and are quite dense. They are sufficiently strong to handle without great breakage. They stand in the air without any tendency to slack, and in the furnace they burn well and hold their form satisfactorily. They burn with a small amount of flame when the fire is first started, but after combustion is well under way, the flame is very slight and there is but little smoke. They burn freely and hold together well. They can be used in anthracite self-feeding stoves, in furnaces, fire places, ranges, etc. For general fuel purposes, these briquettes will give very satisfactory results.

Laboratory No. 2,886 B. These briquettes were made from raw lignite which had been dried, but from which the gas had not been removed. The following mixture was used:

12 per cent coal tar pitch, abqut 145 degrees melting point.
2 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
81 per cent raw lignite, dry.

Their composition was as follows:

	As rec'd, per cent.	Dry, per cent
Moisture	11.38	....
Volatile combustible matter	29.81	33.20
Fixed carbon	48.48	54.00
Ash	10.33	12.80
	100.00	100.00
British thermal units per pound	10,490	11,837

Laboratory No. 886 C. These briquettes were made from raw lignite which had been dried, but from which the gas had not been removed. The following mixture was used:

10 per cent coal tar pitch, about 145 degrees melting point.
4 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
81 per cent raw lignite, dry.

Their composition was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	7.61	....
Volatile combustible matter	31.32	33.70
Fixed carbon	51.67	55.60
Ash	9.40	10.70
	100.00	100.00
British thermal units per pound	10,900	11,797

Nos. 2,886 B and 2,886 C are both made from raw lignite. The difference being that the per cent of pitch in B is 2 per cent higher than in C, while the per cent of flour in C is 2 per cent higher than in B. I consider the B the more desirable briquette. These briquettes are so nearly of the same character and composition that the following statements apply to both alike:

They are probably strong enough to stand handling to a limited degree, but they are not as strong as the briquettes made from carbonized lignite residue. They are, however, both very good for raw lignite briquettes. The waste in breakage where there is much handling would be higher than in the briquettes made from carbonized lignite. The color is almost black, and there is comparatively little shrinkage. They stand well in the air, but in the fire they tend to crack considerably, without, however, disintegrating. There is a large volume of flame and considerable smoke, but after the fire is well started the smoke is not as noticeable. These briquettes may be considered very good considering the fact that they are produced directly from raw lignite, but it is very doubtful if raw lignite briquettes will prove to be generally satisfactory for commercial use.

Laboratory No. 2,888. Briquettes made from partly carbonized North Dakota lignite. The carbonization was carried on in a modified bee-hive oven; and Texas petroleum residue was used as a binder instead of coal tar pitch. The following mixture was used:

6 per cent Texas petroleum residue.
2 per cent ground screenings, or low grade flour.
5 per cent bituminous coal.
87 per cent partly carbonized North Dakota Lignite.

The composition of these briquettes was as follows:

	As rec'd, per cent.	Dry, per cent.
Moisture	7.50	....
Volatile combustible matter	15.35	16.50
Fixed carbon	61.30	65.90
Ash	15.85	17.60
	100.00	100.00
British thermal units per pound	12,140	12,984

In this sample the ash is unusually high because of the fact that some of the residue was reduced to ash in the burning and quenching. Under ordinary conditions, the ash would be considerably lower. These briquettes have excellent physical qualities. They are very strong and hard and stand exposure to the air without any tendency to slack. They are almost jet black in color, have an excellent surface, and are very dense. They stand handling remarkably well and there is very little breakage. In the fire they stand well and hold their form satisfactorily, although they do not seem to be quite as hard as the briquettes made with coal tar pitch. They burn with a small flame and but little smoke. They would make an excellent substitute for anthracite in self-feeding stoves, and would also be an excellent material in furnaces, fire places, ranges, etc. For general fuel purposes these briquettes would give excellent satisfaction. This test was run for the purpose of determining the value of Texas petroleum residue as a substitute binder for coal tar pitch, and the sample which we made this test with has proven very satisfactory for this purpose. The briquettes are not quite as hard as those made from the coal tar pitch, which we have described and used in other tests in this report; but they are very tough and elastic, and I think would stand handling fully as well as briquettes made with the same precentage of harder but more brittle coal tar pitch, and would give less breakage.

This Texas petroleum residue works very satisfactorily and produces an excellent briquette. It has an advantage in the fact that it produces much less black smoke than coal tar pitch does.

Conclusions.

The results obtained in these tests would indicate that the methods which we have worked out and which are applicable to North Dakota lignites, can also be used with a fair degree of success on your Texas lignites. The special characteristics of the Texas lignites require slight modification in the commercial application of this process, but no material changes in principles or methods.

On account of the climatic conditions and the cost of fuels, it is probable that the type of briquette should be slightly different from that which would be considered most desirable commercially in North Dakota. The main difference would probably be in the degree to which the carbonization should take place, and possibly in the use of crude petroleum residue, if it can be obtained in sufficient quantity and at sufficiently low price, as a substitute for coal tar pitch.

By reference to the earlier part of this report, it will be seen that the samples of air-dried Texas lignite will produce, per ton, from 9,000 to 11,000 cubic feet of gas of about 335 B. t. u., unpurified. Although the heat value is somewhat low, the yield is very good. It is probable that if this coal were completely dried before carbonizing and the carbonizing were done at a somewhat lower temperature, the gas would be of higher heating value but of correspondingly smaller yield. Moreover, if the gas were purified, as with ordinary city gas, its B. t. u. would be considerably raised.

In commercial practice it would probably be more economical to dry the coal in a rotary drier before carbonizing it, as this would increase the rapidity of carbonizing and the quality of the product. By so doing, it is probable that a yield of 8,500 to 9,000 cubic feet of gas could be counted on in a commercial plant.

This gas is valuable for heat and power purposes and if used with a 'mantle' is excellent for lighting. Considering the ease with which it can be produced and the low cost of the original lignite and the value of the resulting residue, such lignite gas should, in many localities, have a good commercial value. If produced as a by-product in connection with the briquetting of lignite, it could be sold unpurified at a very low price, especially if used for heat and power gas. A very few cents saving on the by-product gas would net a considerable revenue per ton of briquettes.

In addition to this, if desired, some saving in ammonia and lignite tar could be effected. The yields of these two substances were not determined on these tests of Texas lignite, but it is not probable that they would vary greatly from the results obtained with North Dakota lignite (see "Investigations of Lignite Coal Relative to the Production of Gas and Briquets," by E. J. Babcock). This lignite tar should have considerable commercial value.

The residue produced after the gas has been extracted is of high fuel value. It is probable that in commercial practice about 50 per cent of this carbonized residue could be obtained per ton of raw air-dried lignite with most of the gas removed. When the binding material is deducted, it will be seen that it will require about a ton and three-quarters of raw coal for a ton of finished briquettes. These briquettes, however, would be of high fuel value and if carbonized to that extent should be an excellent substitute for anthracite coal. Such briquettes would have many advantages over the raw lignite. They would be much higher in heating value, they would not disintegrate when exposed to the air or on burning, would be uniform in size and convenient to handle and would be of high economic value.

The results of these tests lead me to believe that in consideration of the climatic conditions in your region, the cost of other fuel and the special characteristics of the raw lignite, it would not be desirable, in many cases, to make a completely carbonized residue briquette, but rather an intermediate quality in which the lignite would be partially carbonized by a cheap and simple process and thus produce a briquette which could be marketed at a much lower price than a completely carbonized residue briquette could be sold for, unless a fair price could be obtained for the gas.

Such a briquette from partly carbonized residue, would prove an excellent steaming fuel and also good for most household purposes. It would be of good heating value, much above the raw lignite and would be sufficiently strong for ordinary handling. These conclusions are borne out, I think, by examination of the accompanying briquettes made from the partially carbonized residue, the tests of which are given in this report.

By such a partial carbonizing process, the moisture and lighter volatile gases would be driven off easily and with little cost and the residue yield would be, of course, correspondingly larger. If these briquettes were made with the proper proportion of binder they would undoubtedly give a satisfactory product for the uses mentioned.

On the other hand, these tests would indicate that it would not be desirable to attempt to produce, for commercial purposes, raw or uncarbonized briquettes. Raw lignite briquettes will not stand the weather or handling very satisfactorily, as will be seen by reference to the samples which accompany this report. They crack and crumble quite readily in the furnace, due to the rapid production and escape of a large quantity of gas which is present in the raw lignite. Furthermore, these briquettes have not as high heat value. Raw lignite briquettes would cost nearly as much to produce as the partially carbonized residue briquettes and would be very much inferior in quality. Therefore, I would not advise any attempt at the manufacture of raw or uncarbonized lignite briquettes.

I believe, however, that by the partial carbonization of the Texas lignite and the use of the proper proportion of "Texas Petroleum Residue," if it can be secured at low enough price and in large quantities, a satisfactory commercial product can be successfully produced in localities or under conditions where there is not demand for all of the gas which would be produced by complete carbonization. If, however, there is a good market for this by-product gas, the more completely carbonized residue briquettes should be produced at a commercial advantage."

This concludes the report of Professor Babcock.

The investigations made by Professor Babcock are the first attempts to bring this matter into the sphere of commercial possibilities. He takes what seems to us to be the only rational view of the situation when he says that it is doubtful if raw lignite can be made into acceptable briquettes. It is not necessary to quote the results of experiments that were made in St. Louis and elsewhere, by the United States Geological Survey, for they do not lead us in the right direction. These experiments looked to the manufacture of briquettes from raw lignite and it seems to us to be quite useelss to hope for a profitable exploitation of this field.

We are decidedly of the opinion that the best, if not the sole, outlook is in the direction of briquettes made from carbonized lignite, whether this carbonization is partial or complete, with recovery of gas, tar and ammoniacal liquor. The development of this industry will, we think, depend on the utilization of all of the products derivable from lignite, viz.: the solid residue, the gas, the tar (and products of its distillation) and ammonia compounds to be obtained from the ammoniacal liquor.

In order to throw some light on this subject, we built in our own laboratory an experimental gas plant for distilling lignite in a closed retort and determining the yield and quality of the products obtained. This investigation was an elaboration of our work on samples of all of the coals and lignites mined in Texas, and was confined to one particular lignite because it was impracticable to conduct so detailed an experiment on more than one sample. This special work occupied us for nearly four months and had we extended it to embrace all other lignites produced in the State, it would have been three years before the work could have been finished.

In this special investigation we were greatly aided by Dr. W. Bredlick, a Bohemian chemist of wide experience in such matters, and our grateful acknowledgments are due him, as also to Mr. J. E. Stullken, assistant chemist to the Bureau. The detailed results of this special work are set forth in Chapter XI.

CHAPTER X.

UTILIZATION OF BROWN COAL AND LIGNITE IN EUROPE.

BY W. BREDLICK.

The utilization of the brown coals and lignites of Europe, by briquetting and by destructive distillation and recovery of the by-products, has reached a high stage of development. This industry may be compared, for the purpose of illustration, to the highly developed petroleum industry in the United States. A barrel of crude oil is worth about $1.00, on the average, but may be made to yield considerably more than this by distillation and refining. The brown coals and lignites of Europe have been enhanced in value by briquetting or made to yield by-products of greater value than the original substance by the process of destructive distillation.

The comparison may be carried still further. Crude petroleum from one district may differ widely from that of another district, even from different wells in the same district, yet these different petroleums can all be refined by similar processes and made to yield products of higher value. In like manner, the brown coals and lignites of Europe, of which there are many varieties and grades, either are or can be utilized, within certain limits, for the manufacture of more concentrated fuels, and for their yield of by-products.

In view of the fact that many of these European fuels, which are thus treated, are not only similar to but some nearly identical with and others even inferior to, the Texas lignites, a description of the industry as developed in Europe is of special interest, because the utilization of Texas lignites will naturally follow similar lines of development. Other chapters of this bulletin give the results obtained in the laboratory of the Bureau by the dry distillation of Texas lignite.

It may be said of lignite that it is a somewhat inferior fuel; that is, its heating power is lower than that of coals in ordinary use. This is due primarily to the fact that lignite contains a much larger percentage of water than ordinary coal, and, also, that it nearly always contains more oxygen and sometimes more ash.

The beneficiation of lignite may be accomplished by mechanical and chemical treatment in three ways.

The first, a purely mechanical treatment, consists in drying the fuel. By driving off the moisture, usually from 25 to 30 per cent, the percentage of the other constituents is raised and the heating power increased. The elimination of the moisture results in partial disintegration of the fuel with the result that it cannot bear transportation or handling. The dried material must consequently be compressed into briquettes either with or without a binder.

The second method is the dry or destructive distillation, a purely chemical treatment. In this process, which is, in principle at least, identical with that used for the manufacture of coke for metallurgical purposes, the lignite is heated with the exclusion of air. The products resulting are as follows:

First. A residue composed of the fixed carbon and mineral contained in the lignite.

Second. The volatile by-products, consisting of gas, tar, and ammoniacal vapors.

The residue is not a coke in the ordinary use of the word, being disintegrated into small pieces instead of agglomerated into masses.

The gas resembles coal gas made in the same manner; the ammonia is, of course, the same. The tar is quite different, as will be shown later.

The oldest distillation plant in Europe is still in operation in Saxon-Thuringen, in Germany.

The third method of treating lignite is that of extraction with solvents. This is a new industry which began to flourish only during the past year. It has found practical application with the bituminous lignites (pyropissit) of the Saxon-Thuringen district. This particular lignite contains a soluble substance which can be removed without the usual decomposition by heat. This has been known since the beginning of pyropissit distillation, but that it can be commercially accomplished on a large scale is a modern achievement. From this lignite the soluble portion is removed by tar oils of low boiling point, made from brown coal. A part of this extract is purified by the Bayens and similar methods. It is used as a substitute for Carnauba wax and is mixed with ceresin. It is black-brown in color and has a conchoidal fracture. It is used for making phonograph plates, for the manufacture of shoe-polish, for sizing paper, etc. Its extraction can be carried on profitably only from lignite containing a certain amount of this waxy substance. However, all kinds of lignite (called brown coal in central Europe) are treated either chemically or mechanically or both, for the purpose of concentrating the heating power or for the recovery of by-products.

As regards their properties for the purpose of treatment, the lignites of central Europe may be classed according to their use into the following groups:

I. Lignites used as fuel without any preparation.
II. Lignites that are briquetted.
III. Lignites that are distilled.

To the first group belongs the young lignite, really a fossil wood, then the common brown coal, and the lignite anthracite. The moisture content of these lignites varies from 10 per cent to 30 per cent. They are all low in ash. This group is represented in all gradations by the Bohemian lignites of the northwest brown coal basin. They are used exclusively under boilers, for generating gas, for all kinds of smelting and for household purposes. Those rich in gas are used for the manufacture of illuminating gas. The only treatment these lignites receive is screening to size them into lump, nut and gravel coal. In Bohemia, some of these lignites are briquetted with the addition of a binder and a small quantity is distilled to obtain lignite coke. The industry is local, however.

To the second group belong the briquette coals. Their moisture content is between 40 per cent and 60 per cent. Since these lignites are not compact and oftimes are slimy from excessive moisture, they are not suitable for fuel in the crude state, except when burned on a special form of step grate or when dried before firing. They are used in briquetting factories for local consumption, usually in factories in the immediate vicinity of the lignite mines. They are found in immense layers, sometimes 120 feet thick at a depth of only 6 to 10 feet below the surface of the earth, consequently they are mined chiefly by open-cut workings. To prepare them for briquetting, when very moist, the larger pieces of wood are removed and then the remainder is disintegrated and sifted to separate out the ashy lignite powder. The homogeneous lignite is then dried in vertical or horizontal cylinders, until it contains only 13 to 15 per cent moisture. Under a pressure of 9 to 11 tons, this dried substance is pressed into briquettes of various forms. The lignites of Germany can be pressed into briquettes that are weather and water proof without the addition of any binding material like tar pitch, or petroleum pitch. These briquettes do not suffer any loss by deterioration on exposure to the air. This is due partly to the nature of the lignite used and partly to climatic conditions. They are used extensively for domestic purposes, not only in heating stoves but also in cook stoves. For boiler heating and gas production, smaller briquettes are made that find a ready sale in central, south, and west Germany.

This lignite, as mined, has a heat value of 3,600 to 4,500 B. t. u. The briquettes made from it will run from 8,300 to 9,700 B. t. u. The cost of mining by open cut workings is on the average 30 cents per ton. This is the cost of the raw material required, since no binder is necessary. The profit in briquetting this lignite consists in raising its heat value from 3,600-4,500 B. t. u. per pound to 8,300-9,700 B. t. u. per pound. To express the relation in cost per ton of briquettes, the following figures are given:

1.92 tons lignite required for 1 ton briquettes, at 40 cents per ton for the raw material	$0.770
1 ton for power	0.435
Labor, depreciation, maintenance, interest on the investment.	0.750
General management	0.125
	$2.080

The selling price per ton in Germany is on the average $2.50, making a profit of 42 cents per ton on the briquettes. A plant with a capital of $110,000 can manufacture 36,000 tons of briquettes per year, clearing a profit of $15,000, or nearly 13½ per cent. Since 5 per cent interest is included in the above calculation under the item of "Labor, depreciation, maintenance, interest on investment," the briquette factory nets a profit of 18½ per cent, on the average.

Other lignites, like those of Bohemia, need a binder, often as high as 8 to 12 per cent being necessary. In general, the older the lignite the more binding material is necessary. West Bohemian lignites are made into briquettes in only three factories. The binder used is pitch. The production in Bohemia is very small in comparison with the output in Germany.

Besides briquetting with a press, there is another method in use in some localities for working lignites. In ordinary briquetting, the heating value is raised 80 to 90 per cent, or more, and the lignite is also fitted for handling and transportation. In the method about to be described, the heat value is raised only 15 to 20 per cent, and the territory of sale is limited to small distances from the point of production. The lignite is spread on a floor. Woody pieces are removed and it is then moistened. The soft mass is then thoroughly mixed by tramping on it. This mass is then placed on a flat surface to the depth of seven inches. It is smoothed, moistened again and is allowed to dry in the open air. It is then tamped down with a wooden tamper and cut into cubical blocks. These blocks are laid in rows under drying sheds. This work is generally done by hand, but can be done by a machine similar to that used in a tile factory. This method of preparing lignite is in use in Hessia, Saxony Province, in the Thuringen States, and in the Kingdom of Saxony. The total production of these hand briquettes in Germany reached its maximum in 1901 with an output of 740,000 tons but was reduced to 583,000 tons in 1906.

The third group of lignites includes those that are utilized through dry distillation, a chemical process in which decomposition is effected by heat. To this group belongs the earthy brown coal with high bitumen content called pyropissit. Bituminous shales are also treated in this way. The brown coal, pyropissit, is worked on a large scale at present only in Saxony-Thuringen, of Germany. It consists of pyropissit and fuel coal. Between these two exists the real distillation coal, called Schwell coal. According to its composition, pyropissit belongs to the wax coal, the fuel coal to the humus coal. In origin, pyropissit must belong to the vegetable waxes and rosins of the Tertiary age. This explains why these substances so strongly resist decay and dissolution and therefore were preserved under conditions under which other parts of plants were completely destroyed. The distillation coal in the damp condition in which it occurs in the mines forms a plastic mass, at times greasy and fatty to the touch. When dry it is of a light color and resembles an earthy brown coal that is soaked more or less with a wax-like bitumen. The deposit, which is mined by open cut, is not homogeneous, but consists of layers of lignites rich in bitumen, pyropissit, and fuel coal.

The other material mentioned for destructive distillation is bituminous shale. It belongs to the sapropel coals and is formed by the addition of clay sediment to the decaying bog. This shale occurs at Messel, near Darmstadt, Germany. The bituminous shale of Scotland resembles that near Darmstadt. The German shale distillation works are not open to the public and the literature on the subject, so far as German practice is concerned, is meager.

The distillation of brown coal and bituminous shale is similar in the sense that in each case a bituminous substance is treated. As has been stated, in the brown coal that contains pyropissit, usually there occurs also the fuel-lignite. It is quite difficult to distinguish between them in a moist condition. Both form a more or less plastic brown mass which, in the case of pyropissit, turns on drying to a yellow or white color, according to its purity. Distilling-lignite, when dry, shows an earthy fracture and feeble gloss. Its specific gravity is 1.0 or less, while that of fuel-coal is 1.2 to 1.4. Distilling-lignite melts at 302 to 392 degrees Fahrenheit (150-200 degrees C.), while fire-lignite never melts but burns with a strong sooty flame and faint odor which changes, on being blown out, to the odor of burnt shellac. Pure distilling-lignite is free from vegetable remains. It consists only of amorphous resinous particles that saponify when treated with an alkali.

The composition of pyropissit, distilling-lignite, and fuel-lignite respectively was ascertained by Brückner as early as 1852.[1]

Through successive extraction with oils and alcohol and afterwards by distillation of the extracts, a whole series of wax or rosin products was obtained. Special names and formulae were given to the isolated bodies. Inasmuch as pyropissit is not a definite chemical compound but a mixture, being a transition product[2] from the resin of plants to fuel-lignite, there is a difference in the analyses given by different chemists. According to Riebeck, pyropissit has the following proximate analysis:[3]

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[1] Jour. für Prak. Chem., Vol. 57, p. 1.

[2] Graefe, Die Braunkohlenteer Industrie, 1906, p. 3.

[3] Zts. für Berg-Hütten und Salinenw., Vol. 24, p. 356.

	Per cent.
Hygroscopic water	4.40
Organic matter	83.97
Ash	11.63
	100.00

Its ultimate analysis is as follows:

	Per cent.
Carbon	66.24
Hydrogen	10.55
Nitrogen	0.01
Oxygen	13.34
Ash	9.86
	100.00

Fuel-lignite has the following composition by ultimate analysis, on an air-dried sample (V. Bredlik):

	Per cent.
Carbon	58.21
Hydrogen	5.09
Oxygen	26.11
Nitrogen	0.54
Ash	0.55
Moisture	9.50
	100.00

The distilling-lignite deteriorates on exposure to the air, as Thede has shown analytically.[1]

If pyropissit be subjected to dry distillation, it is decomposed, according to Riebeck, into

	Per cent.
Tar	64.2
Water	7.7
Coke	16.3
Gas and loss	11.8
	100.0

Distilling-lignite, on the other hand, yields

	Per cent.
Tar	33.0
Water	23.0
Coke	35.0
Gas and loss	9.0
	100.0

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[1] Allgem. Oesterr. Chem. u. Techn. Ztg., 1892, p. 917.

Fuel-lignite yields by distillation:

	Per cent.
Tar	5.0
Water	63.5
Coke	25.0
Gas and loss	6.5
	100.0

From these figures, it is seen that these substances give different yields of tar. In former times, great care was taken to separate the distilling-lignite from fuel-lignite. To the pure pyropissit, fuel-lignite had to be added, since, when alone in the distilling oven, it melted and flowed, making distillation difficult. At the present time, the supply of very bituminous lignites has been exhausted and the operator must be satisfied with a much poorer grade for distillation. Those now treated by this method yield but 5 per cent tar. The primary purpose of distilling these lignites is to obtain tar through the decomposition effected by heat. In Saxon-Thuringen the lignite coke is the by-product.

Formerly, the lignite was distilled in cast iron retorts. Since 1858, vertical coke ovens have been used exclusively. They are about 18 feet high. Within is a system of beveled cast iron rings placed one upon the other in the form of a column. A cross section gives an appearance of Venetian blinds. These flanges are fastened to each other in the central axis by a vertical rod passing through the cylinder. Inside this cylinder then a hollow space is formed about 4 feet in diameter. This column of circular flanges is walled in with a fire-proof material called Dinas tiling. The space between this shell of tiling and the column of flanges is about 6 inches, and is the space occupied by the lignite during the process of distillation. The flame from the burning gases for distilling the lignite passes upward through spaces provided in the Dinas tiling, which is so constructed that it is in reality a hollow column with passages so arranged that the flame instead of going directly upward is forced to follow passageways around, spirally. The lignite is distilled by coming in contact with this heated tiling and in reality is heated by radiation, the flame not coming in contact with the lignite. The exterior of this Dinas tiling is enclosed with fire brick and these in turn with ordinary brick. At its lower end the distillation cylinder is conical. To this cone is joined a round box. The top of the cylinder is covered with an inverted funnel-shaped hat. Two pipes carry off the products of distillation, one in the upper part and one in the lower. Outside they unite and carry the distillation products to the condensing apparatus. The lignite is charged at the top and passes vertically downwards between the cast iron rings and the heated tiling. The oven is fired with the gas produced by distillation after the gas has passed through the condensation apparatus and has been relieved of its tar and ammonia contents. The temperature is lowest in the upper portion and distills off the water first. As the lignite sinks it encounters the hotter part of the furnace. Distillation occurs in the lower third of the oven. At the bottom of the oven the residue, a lignite coke, is drawn off and quenched with water. The temperature from the top to the bottom increases gradually to a maximum of 1,184 degrees Fahrenheit (640 degrees C.). Gas begins to form at from 248 to 302 degrees Fahrenheit (120 to 150 degrees C.), is drawn from the interior space of the oven by means of an exhauster and passed to the condensation plant, through the two pipes mentioned above.

The condensation plant consists of a system of pipes through which passes the gas with its burden of tar. Cooling was formerly done with air, but of late water cooling has been introduced to save space and to lessen the amount of piping necessary. The condensed substance flows into a reservoir.

Distillation-lignite now being treated yields about 4,900 cubic feet of gas per ton, with a heat value of 310 B. t. u. per cubic foot. The gas has:[1]

	Per cent.
Carbon dioxide	10.9
Heavy hydrocarbons	1.1
Oxygen	6.3
Carbon monoxide	8.5
Hydrogen	22.6
Methane	6.4
Ethane	2.0
Nitrogen	42.2
	100.0

Formerly the gas was allowed to escape into the air. Today it is used to heat the ovens and the surplus is utilized in gas engines for the generation of electric energy.

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[1] Graefe, J'l für Gasbeleuchtung u. Wasserversorgung, 1903, p. 524.

The ammonia is not conserved, since only 0.07 per cent is found in the condensed water, in the Saxony-Thuringen industry.

The coke is a granular product of pale black color, containing 15 to 20 per cent ash and 20 per cent water (from quenching) and has a heat value of 8,500 to 9,000 B. t. u. If burned in a suitable furnace, it is an excellent fuel that emits no smoke, deposits no soot and has no flame.

The principal product in point of value is tar. When warm it is a liquid, when cold it grows stiff to a buttery consistency. It has a brown color and an aromatic odor. Its specific gravity is between 0.85 and 0.91. The lighter the tar the greater is the paraffin content and therefore the greater its value. Tar boils between 302 degrees Fahrenheit (150 degrees C.) and 752 degrees Fahrenheit (400 degrees C.), but contains a small quantity of substances of lower and higher boiling points. It consists chiefly of liquid and solid members of the paraffin and olefin series, and other hydrocarbons of low hydrogen content. Of aromatic substance it contains only traces of benzol and its homologues. Besides these there occur small quantities of free acids and their esters with alcohols of high molecular weight, derived from undecomposed bitumen. An integral constituent of lignite tar is sulphur in organic combination. Coal and coke dust as well as water are found in tar as impurities. To separate the water, the tar is collected in pits where it remains warm and fluid for some time, which permits the suspended water to settle out.

The tar, after the water has been separated, is treated for tar oil and paraffin and the by-products gas, cresole, and coke. This is effected by (1) fractional distillation, (2) chemical treatment of the distillates, and (3) crystallization. The method of treating the tar from bituminous lignites in Saxony-Thuringen, the tar from bituminous shales, and the tar from the Bohemian lignites, is pretty much the same. For this reason, the method common for all will be described.

The Scottish industry since 1872 has used exclusively a bituminous shale as a distillation material. This is found in Linlithgow and Mid-Gotham counties. It is deposited in the lower bituminous coal formation, not between layers of coal, but between limestone and sandstone. A distinction is made between two kinds of shale, one which has a shale-like fracture and is gray, while the other has a conchoidal fracture and is black. In a moist condition it has a greasy feel and is tough, with the odor of clay. When dried it is shaly and with leaflike layers. The chemical composition of Scotch shale is as follows:[1]

	Per cent.
Carbon	25.27
Hydrogen	3.67
Oxygen	5.65
Nitrogen	1.14
Sulphur	0.49
Ash	63.74
	99.96

The bituminous shale of France is analogous to boghead coal, compact and massive like compressed peat, and has about the following composition:[2]

	Per cent.
Carbon	60.80
Hydrogen	9.18
Nitrogen	0.78
Oxygen	4.38
Sulphur	0.32
Ash	24.18
Moisture	0.39
	100.03

The bituminous shales which are distilled in Germany, France, England, etc., differ from the distilling-lignites of Saxony-Thuringen in composition and in yield of the principal by-products. In the case of the lignites, the principal product is tar, the by-products are coke and gas. Shale is distilled for tar and ammonia, and the by-products, coke and gas, are not considered. Since shale in England contains 60 per cent, in Germany 50 per cent, and in France 24 per cent of mineral matter, the residue from the retorts is of little value as a fuel. The yield of gas is not sufficient even to supply the necessary fuel for distillation and the retorts must be heated with coal direct or with producer gas.

The following summary shows the yield of different bituminous shales, in percentages:

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[1] Destruct. Distill. Mills, p. 38.

[2] Dict. de Chemie, Wurz, Vol. I, part 1, p. 638.

	Tar.	Ammonia water.	Residue.	Gas.
(1.) Messel, Hessia, Germany	6–10	40–45	40–50	....
(2.) Broxburn, England	12	8	76	4
(3.) Bagnas and Autunois, France	6	10	81.5	2.5
(4.) Subotioi, Servia	34	8	36.53	11.47

The distillation apparatus used in the shale industry is quite different from that employed in Saxon-Thuringen. Essentially it consists of a vertical cast-iron cylinder, from 12 to 14 or even to 16 feet in height, and from 1½ to 3 feet in diameter. It is heated directly with coal or with producer gas supplemented with the gas from the distillation. In order to obtain the greatest possible yield of ammonia, superheated steam is blown into the retorts. By this means, the fixed carbon present is consumed. The gases are drawn off by suction and condensed by air and water cooling and by washing the gas in paraffin oil. The cooled gas is also compressed to obtain liquid hydrocarbons.

The gas of the Scotch industry has the following composition:[5]

	Per cent.
Carbon dioxide	15.40
Carbon monoxide	10.72
Hydrogen	34.53
Methane	4.02
Nitrogen	35.33
	100.00

One ton of shale yields about 3,000 cubic feet of gas. If the distillation residue contains some carbon, it is burned and the ash used to make bricks. The tar of the Scotch industry from retorts of the older system (without the use of superheated steam) had a specific gravity of 0.88 to 0.90, the tar of the new system (with superheated steam) has a specific gravity of 0.85 to 0.875. It stiffens at 50 to 68 degrees Fahrenheit (10 to 20 degrees C.). Its color is brownish red, the odor is mild, and it boils from 158 to 752 degrees Fahrenheit (70 to 400 degrees C.). Its composition is similar to that of the lignite tar of Saxon-Thuringen, except that its nitrogen content is higher, 1.16 to 1.45 per cent.[6]

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[1] Scheithauer, Die Fabrik der Mineralöle, p. 28.
[2] J'l Soc. Chem. Indust., Vol. 8, p. 100.
[3] Dict. de Chemie, Wurz, Vol. 1, p. 638.
[4] "Verlag Berliner," 1887, p. 2717.
[5] J'l Gas Lighting, 1893, Vol. II, p. 399.
[6] J'l Soc. Chem. Indust., 1891, p. 126.

The yield of ammonia is high in comparison to the yield in other distillation processes, being increased by blowing in the superheated steam. According to Young and Beilby, the nitrogen content of the crude material is as follows:[8]

	Per cent, without steam.	Per cent, with steam.
As ammonia in ammonia water	17.0	74.3
Nitrogen in tar	20.0	20.4
Nitrogen in residue	62.6	4.9

The specific gravity of the water is 1.03, and it contains, besides ammonia, pyridine and other organic bases. The water is usually distilled out in horizontal cylindrical vessels, after adding 5 per cent slaked lime. The vessels have a capacity of 175 to 560 cubic feet and are heated by direct fire or by indirect steam. The gaseous ammonia goes through a scrubber and is passed into a trough lined with lead and containing sulphuric acid of 1.4 specific gravity. The crystals of ammonium sulphate formed are dried by decantation. They are not quite pure but contain some free sulphuric acid, traces of sulphurous pyridine that does not crystallize, and a little water.[1] One ton of shale yields 59 pounds of ammonium sulphate, from which 15 pounds of ammonia is derived.

As already stated, the working of the tar of the German lignite distillation and shale distillation is practically the same and for this reason the two processes will be described together.

Lignite distillation and shale tar distillation may be considered under three heads:

1. Fractionating distillation.
2. Treatment of the distillates with chemicals.
3. Manufacture of paraffin.

After the coal tar has been freed from moisture, coke and coal dust, it is subjected to the first distillation, yielding the following fractions:

I. Paraffin-free oil.
II. Paraffin mass.
III. Residue.

The distillation is made in a cast-iron retort of 70 to 100 cubic feet capacity, which has a special discharge for the residue.

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[8] Zeitsch. für angew. Chem., 1893, p. 108.

[1] Destruct. Distill. Mills, p. 20.

The retort has a fire-brick setting and the firing is done on horizontal stationary grates.

The first part of the distillation is carried on under atmospheric pressure. When the water has been removed, the distillation is continued under vacuum, about two-thirds of the distillation being done in this way. The products are separated into paraffin-free oil and paraffin mass. These are distinguished in this way. The paraffin-free oil comes over first. Samples are repeatedly taken and allowed to drop on ice. As soon as the oil stiffens, indicating the presence of paraffin, the receiver is changed.

The tar is seldom distilled to dryness, that is, to coke, in the same retort. Usually about two-thirds is distilled off and the remainder is discharged into another retort and there dried to coke. In this way, there are fewer retorts to be heated to a high heat, and there is also a higher yield of paraffin. These second retorts are similar to the first except that they do not have the pipe for emptying at the bottom. The residue of coke is removed by chipping it off.

This second distillation is also made under reduced pressure. The reduction in pressure is made either by means of the Körting steam exhaust or with a pump.

In this pitch retort the hard paraffin mass is obtained. Toward the end of the distillation as a result of the destruction of pyrogene there appear greasy reddish brown masses, the so-called red products. These must be carefully separated from the paraffin mass, since they interfere with the purification of the paraffin. They contain a considerable amount of aromatic hydrocarbons, principally picene and chrysene. Anthracene has not been proven to be present. While the retort is glowing hot there appear great masses of gas which are drawn off by the vacuum pump.

The first gases to be removed are those that have been absorbed, especially hydrogen sulphide. Then follow products due to pyrogene destruction. The gases by weight amount to about 2 per cent, so that one ton of pitch will yield from 30,000 to 40,000 cubic feet of gas.

The analysis is as follows:

	Per cent.
Lighter hydrocarbons	3.0
Hydrogen sulphide	3.2
Carbon dioxide	2.4

	Per cent.
Heavier hydrocarbons	6.8
Oxygen	3.4
Carbon monoxide	1.9
Hydrogen	4.9
Methane	28.5
Ethane	32.2
Nitrogen	13.7

These gases may be used for lighting, after the hydrogen sulphide has been removed. Otherwise they are used for heating and lately they are used as fuel for gas engines. Ten cubic feet will generate one horse-power per hour.

The distillation residue, which amounts to 2 per cent of the tar, is coke. Since it contains but a trace of ash, it finds a market as carbon for electric purposes, after being freed of undecomposed hydrocarbons by heating to redness.

A tar having a specific gravity of 0.86, yields the following products during the first distillation:

	Per cent.
Moisture	some
Paraffin free oils	30.0
Paraffin mass	64.0
Red products	2.0
Coke	2.0

Of the 64 per cent paraffin mass, 20 to 25 per cent is paraffin.

All distillation products of tar are treated chemically before being worked further; some are treated several times in their different fractions, after a second or even a third distillation. The chemicals ordinarily used are sulphuric acid of 50 to 60 degrees Baumé, and sodium hydrate, 38 degrees Baumé. The products are washed in the following order.

1. Treated with 50 degree acid.
2. Treated with 60 degree acid.
3. Washed with hot water.
4. Treated with a small amount of 38 degree sodium hydrate.
5. Treated with a large amount of 38 degree sodium hydrate.
6. Washed with hot water.

The tar distillates are washed with dilute sulphuric acid to remove the last trace of water and to wash out the basic components. such as pyridine bases. They are treated with 66 degree Baumé sulphuric acid to remove the coloring components, not only those present as such, but also those which although originally colorless will cause the products to darken when stored away. The part played by the 66 degree acid in this washing is quite complicated from a chemist's point of view.

After the distillates have been treated with sulphuric acid, they are washed with water and then with sodium hydrate. This is done to fix the dissolved and suspended reaction products, but especially to remove the phenol-like bodies, especially all the homologues of the phenols.

After the treatment with hydrate solution, wash water is again applied. Washing the distillation products is carried on in large covered or uncovered cylinders or vats lined with lead. At the lower part a conical base is soldered on. Mixing is done by means of a horizontal or vertical propeller or better still, by means of compressed air, which can also be used to transport the liquid tar products and the chemicals. The reaction products obtained are acid rosins and sodium creosoles.

The acid rosins are boiled with steam in lead-lined vessels. By this means, the sulphuric acid formed by splitting of sulpho-acids is removed as a brown acid waste of 30 to 40 degrees Baumé. This is then used to decompose the sodium cresoles. During this decomposition, crude creosote and a solution of sodium sulphate are formed. The separated rosin and crude creosote are mixed together and distilled, the products being creosote oil and tar asphalt. The paraffin mass and the distillation products of the paraffin-free oil, i. e. benzene and photogen, are washed in a similar manner.

The loss in washing consists of:

	Per cent.
Benzene	4
Photogen	4
Raw oil	15
Paraffin mass	10 to 11

The washed crude oil is fractionated in similar retorts into:

1. Light brown coal tar oil, specific gravity 0.79-81; flash point 77 to 85 degrees F. (25 to 35 degrees C.); boiling point 212 to 392 degrees F. (100 to 200 C.).

2. Light crude photogen, specific gravity 0.835 to 0.840; flash point 86 to 104 degrees F. (30 to 40 degrees C.); boiling point 302 degrees F. (150 dgrees C.).

It gives, up to 392 degrees F. (200 degrees C.), 35 per cent distillate; up to 482 degrees F. (250 degrees C.), 60 per cent; and the remainder up to 572 degrees F. (300 degrees C.).

3. Clear paraffin oil, specific gravity 0.83 to 0.865; boils between 428 and 608 degrees F. (220 to 320 degrees C.).

The light brown coal tar oil, after being washed, is fractionated again into benzine (colorless, specific gravity 0.790 to 0.805) and solar oil (colorless, specific gravity, 0.825 to 0.830), with boiling point 302 to 338 degrees F. (150 to 175 degrees C.). The crude photogen and the clear paraffin oil are fractionated the same way as the light tar oil. The fractionating distillation is done in the column apparatus known to the petroleum and coal tar industries.

The crude petroleum products of different specific gravity, boiling point, etc., are fractionated according to special demands of the market, and are given different trade names, as "cleaning oil," "gas oil," yellow oil," etc.

The residue of the fractionation is added to the pitch and treated as already described. The paraffin mass after chemical treatment is cooled to 29 to 25 degrees F. (—3 to —7 degrees C.), whereby paraffin is crystallized out. The congealed mass is pressed in a hydraulic press. The separated oil, called press oil, is fractionated as already described. The residue from the distillation of this oil is a tar known as *goudran*.

The following scheme represents the treatment of lignite tar. The commercial petroleum products are in bold-faced type.

TAR
- 1. Crude oil
  - **Gas oil**
  - Light photogen
    - **Benzine**
    - **Solar oil**
    - **Cleaning oil**
    - Residue
      - **Yellow oil**
      - Residue
        - **Hard scale**
        - **Coke**
- 3. Red products.
- 4. Coke and gas.
- 2. Paraffin mass
  - Hard paraffin scales
  - Press oil
    - Heavy photogen
      - **Light photogen**
      - **Red oil**
    - **Gas oil**
    - Soft paraffin mass
      - **Soft scale**
      - **Paraffin oil**
    - Hard paraffin mass
      - **Hard scale**
      - Press oil
    - **Goudran**

The paraffin scales, separated from the oils by pressing, are treated in the same manner as the paraffin scales of the petroleum industry. A description is unnecessary since the American practice is well known. It should be mentioned, however, that the paraffin scales of the petroleum industry contain no homologues of the phenols, while those of the lignite tar industry do contain these homologues in considerable quantities, 10 to 15 per cent. When washed with sodium hydrate, a disagreeable odor is sometimes perceptible and a yellowish color in the light that can be removed only by refining. The lignite paraffin, therefore, must be treated more thoroughly with benzine and decoloring powder (potassium ferrocyanide, potassium ferricyanide and pulverized clay) than is necessary with the paraffin from petroleum.

It has been shown that from the lignite tar are manufactured oils, paraffin, and coke. A brief description of them and their uses is as follows:

Benzine is a colorless liquid with a bluish fluorescence, specific gravity 0.790 to 0.810, boiling point between 230 and 392 degrees F. (110 to 300 degrees C.). It is largely used in the manufacture of paraffin.

Solar oil, a colorless liquid, specific gravity 0.825 to 0.830, boiling point 284 to 464 degrees F. (140 to 240 degrees C.), can be used in lamps instead of kerosene, only it requires a strong draught like Russian coal oil; the reason for this being that the percentage of carbon is higher than in ordinary American kerosene. Its principal use is in explosion motors.

Cleaning oil shows a yellowish luster. The specific gravity is 0.850 to 0.865, boiling point between 392 and 575 degrees F. (200 and 300 degrees C.). It is used for cleaning fatty substances; for example, the extraction and prepration of wagon grease.

Yellow oil and red oil have a still darker color than cleaning oil, specific gravity 0.865 to 0.880, boiling point between 392 and 617 degrees F. (200 to 325 degrees C.). They are used in the preparation of oil gas.

Gas oil, reddish brown color, specific gravity 0.880 to 0.900, is used as the name indicates, for generating gas. One ton of gas oil yields 16,000 to 20,000 cubic feet of gas, 30 to 40 per cent tar, and 3 to 8 per cent coke, depending on the temperature of the retort and the rapidity of the process. The gas has an illuminating power of 8 to 12 candles, when using 1¼ cubic feet per hour. Gas oil is also used to enrich water gas.

Paraffin oil, specific gravity 0.900 to 0.930, has about the same uses as yellow oil, red oil and gas oil. With the rapid increase in the use of the Diesel engine in Germany, a new and almost exclusive market has been found for this oil as fuel for this motor. The Diesel engine utilizes about 30 per cent of the heat energy of the oil, which has a heating power of 18,000 B. t. u. per pound. In 1901, about 5,600 tons of this oil were consumed in Diesel engines in Germany. It is also used as a lubricating oil.

Goudran, a glossy deep black mass, brittle and of conchoidal fracture, melts at 158 to 212 degrees F. (70 to 100 degrees C.), and dissolves completely in benzol. It is used, in addition to natural asphalt, in the manufacture of varnish.

Paraffin, specific gravity 0.874 to 0.915, melting point 99.5 to 136.4 degrees F. (37 to 58 degrees C.), has a crystalline structure, is transparent, of bluish tint, tasteless and odorless. The harder varieties have a slight ring when struck. The most general use of paraffin is in the manufacture of candles. It is also used for impregnating paper, for dressing leather, fabrics and turned railings made of vegetable and animal fiber, etc. It serves as a protective coating against acid and alkali, and as a covering for easily oxidized bodies.

Soft paraffin mixed with clay is used as a finish for glazed paper. It is also used to absorb the odor of flowers in the manufacture of perfume and lotions. In glass-blowing it is used to fill the lamps and in the hard glass factory it is used in the cooling baths. In electric wiring it serves as an insulator. The production of paraffin is increasing, for it can serve many purposes and as an article of commerce it is always saleable.

According to Scheithauer, the products from lignite tar may be expressed as follows:

	Per cent.
Benzine	To 5
Solar oil	5–10
Light paraffin oil	10
Heavy paraffin oil	30–50
Hard paraffin	10–15
Soft paraffin	3– 6
Goudran	3– 5
Coke, gas, water and waste	20–30

The process of distillation of the tar from bituminous shale is quite similar to that of lignite. The same methods are employed, with one exception. In the Saxon-Thuringen tar there are three fractionations—paraffin-free oils, paraffin mass and red products—but in the Scotch and German tar distillations from bituminous shales, the oils and paraffin mass are mixed together and only the red products are separated out.

The various products derived from Scotch shales are shown in the following scheme:

- CRUDE OIL
  - 3. Coke.
  - 2. Red products.
  - 1. Distillate
    - Heavy oils
      - Hard scale
      - Green oils
    - Light oils
      - 1. Naphtha
      - 3. Burning oils
      - 2. Intermediate oils
        - Oils of specific gravity 0.850
        - Blue oils
          - Soft scale
          - Lubricating oils

It is worthy of note that a gas is generated during the distillation of shale tar and that it differs from that of lignite tar in composition. It has an illuminating power of 36 candles. According to Beilby, its composition is as follows:[1]

	Per cent.
Carbon dioxide	none
Oxygen	none
Heavy hydrocarbons	14.5
Carbon monoxide	none
Methane	59.0
Ethane	26.5
Hydrogen	trace

The percentage of heavy hydrocarbons is sometimes as much as 20.6.

The yield of single products in Scotland is as follows:

	Per cent.
Naphtha	4.0
Light oil	25.0
Intermediate oil	15.0
Lubricating oil	8.0
Hard paraffin	8.0
Soft paraffin	4.0
Red products	1.0
Coke, gas, waste	35.0
	100.0

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[1] The Chemistry of Illuminating Gas, Humphry, p. 172.

The distillation scheme for the treatment of tar from German bituminous shales is as follows:

- **TAR**
  - **Oils**
    - **Naphtha**
    - **Gas oil**
  - **Paraffin mass**
    - **Hard paraffin**
    - **Press oil**
      - **Gas oil**
      - **Soft paraffin**, **Crude mass**
        - **Paraffin scale**
        - **Gas oil**
        - **Crude oil or lubricating oil**
          - **Cleaning oil**
          - **Fat oil**
          - **Spindle oil**
          - **Lubricating oil**
          - **Crude mass**
  - **Coke**

The yield is as follows:

	Per cent.
Naphtha	4.0
Gas oil	50–55.0
Crude paraffin	12–15.0
Coke, gas, waste	33.0

Note: The descriptions of the lignite tar and shale tar distillations are taken from Scheithauer's "Die Fabrikation der Mineralöle," and from Graefe's "Die Braunkohlen Industrie."

Having described the bituminous lignite and bituminous shale distillations, there remains to be described the distillation of Bohemian lignite. This is of special interest since it resembles very closely the Texas lignites.

The first attempts to utilize Bohemian lignite through dry distillation were made during the last forty years of the preceding century. Why the work was abandoned is not known, but it was probably due to the fact that these efforts were for the purpose of obtaining tar for paraffin manufacture only, without regard to the utilization of the gas, ammonia, and coke.

The Bohemian lignite yields 5 to 10 per cent tar by dry distillation, while the pyropissits of Saxon-Thuringen yield from 50 to 60 per cent tar. A distillation plant on a large scale was established in Aussig on the Elbe, by a Hamburg bank, in 1895. Originally, the object was to distill a mixture of English bituminous coal and Bohemian lignite to make coke for metallurgical purposes. As long as the price of bituminous coal in England was low, and the price of coke in Bohemia was high, all went well. In the second year, the price of English coal became so high that the plant sustained a loss. The coke works were used then entirely for distilling lignite. The lignite was distilled in vertical coke ovens (modified Appolt ovens), yielding tar and ammonia as by-products. The surplus gas, which amounted to 40 per cent, was used partly as a fuel under the boilers and partly in gas engines. The residue from the distillation, a lignite coke, was used mostly for steam heating and as a fuel in general. Only a part of it was made into briquettes with the addition of tar pitch as a binder. Since the plant at Aussig was not designed for lignite distillation in the first place, and furthermere, since there were gross errors in its construction, a loss was sustained. When the price of lignite increased, the plant resorted to the purchase of dusty waste lignite. On this account, the quality of the coke suffered and the yield of by-products diminished. Finally, changes were made in the construction, but the main drawback was the distance from the lignite mines and the cost for freight could not be reduced. The result was plants were established in the lignite districts, and the old plant was used only for working the by-products. Although the production of ammonia was satisfactory, the results from the tar distillation were not. The mistake lay in not understanding how to treat the tar, since the tar from Bohemia (and also from Texas lignite) is quite different from that of Saxon-Thuringen. It is in reality a transition product between the Saxon-Thuringen tar and coal tar, and of course should be treated as such.

The three plants that had been established in Bohemia came into the possession of people who own practically all the lignite mines of Bohemia. As soon as they came into possession of the lignite mines, they closed down the lignite distillation works with one exception. The lignite is sold as a fuel directly to consumers only, and no lignite is sold to any distillation works because the by-product coke is a competitive fuel with the raw lignite. The one plant continued to treat about 125,000 tons of lignite per annum, but lignite coke briquettes are not to be seen in Bohemia; all are exported to Germany. The by-products, tar and ammonia, are utilized, the surplus gas is used in gas engines to generate electric power which is supplied to neighboring lignite mines.

The lignite distilled in Bohemia at present comes from the vicinity of Teplitz and has an average specific gravity of 1.15. It is screened and the ¼ to ½ inch sizes are used for distillation. An average of thirty-eight analyses is as follows:

	Per cent.
Moisture	27
Volatile combustible matter	30
Fixed carbon	35
Ash	8
	100

Upon distillation, this lignite yields the following products:

	Per cent.
Coke (residue)	43.0
Tar	4.8
Ammonia water	30.0
Gas	22.2
	100.0

One ton yields 6,350 cubic feet of gas, the analysis of which is as follows:

	Per cent.
Carbon dioxide	21.60
Oxygen	2.60
Carbon monoxide	7.20
Methane	22.86
Hydrogen	20.00
Nitrogen	25.74
	100.00

The heat value of this gas is 300 to 350 B. t. u. per cubic foot. The ammonia water contains 0.23 per cent of ammonia, hence one ton of raw lignite yields 1.4 pounds of ammonia which corresponds theoretically to 5.6 pounds of ammonium sulphate. Allowing for a 5 per cent loss in the manufacture, the yield is 5.3 pounds per ton. The residue contains 17 per cent ash, 3 to 4 per cent moisture, 3 per cent volatile combustible matter. Its heat value is 11,000 to 12,000 B. t. u. per pound. If good lignite is used, having a low ash content, an excellent residue is obtained that has a heat value of 13,000 B. t. u.

In Scotland the purpose of the distillation is to obtain tar and more especially ammonia; in Saxon-Thuringen the yield of tar is the impoitant item; but in Bohemia, just as in the distillation of bituminous coal, coke is the principal object, the by-products are tar, ammonia and surplus gas.

As already stated, the distillation of lignite is carried on in vertical ovens which are heated by firing with a portion of the gas made in distilling the lignite.

Of the gas resulting from the distillation, 6,350 cubic feet per ton on the average, 60 per cent. is used for heating the ovens, 40 per cent being surplus gas, which can be used for other purposes, such as the generation of electrical energy, etc.

According to observations made at Aussig, one horse-power hour requires 35 cubic feet of this gas if used in a gas engine. In a recently installed lignite distillation plant, where about 270 tons are worked up daily, there is a gas surplus of 680,000 cubic feet. This corresponds to about 20,000 horse-power hours. To utilize this energy a central power station was established of 1,000 horsepower. The gas engines are directly connected with the generators and after deducting the power required at the plant, the remainder is sold to neighboring cities.

The ammonia condensation plant is according to the Feld system (patented in the United States and England). In this system the gas is not cooled to low temperature and thus a mixture of ammonia water and tar is obtained. The condensation is partial only depending on the dew point of the tar and ammonia. By this method of procedure, we do not obtain a tar mixture but a series of fractional components which are limited in their condensation to their boiling points, those of high boiling point being condensed first as the temperature of the gas is gradually lowered. Since the gas is not cooled under the dew point of water while these oils are condensing out, they are obtained free from moisture. The separation of water occurs in a special washer at a temperature of 140 to 203 degrees F. (60 to 95 degrees C.), at which temperature no ammonia compounds with sulphur can be formed. In a second washer cyanic acid is removed with precipitated iron oxide in the presence of lime (the lime prevents absorption of ammonia) with the formation of iron cyanide. The gas being free from tar, from cyanogen and the most of the water (only 2 grams per cubic foot remaining) the separation of the ammonia is effected. This is done in the last washing at a temperature of 113 degrees F. (45 degrees C.), and with the aid of the carbon dioxide in the gas. The gas is washed in a solution of milk of gypsum (finely ground sypsum suspended in water). The reactions result in ammonium sulphate in solution and carbonate of lime which precipitates out. According to Köhler, this method (the Feld process) is in successful operation in the United States at a plant in New York City.[1]

The coke is cooled in an air-tight vessel. The greater portion is sold as a fuel for making steam (under forced draft) or for the manufacture of producer gas, for which it is well suited, being practically free from volatile tar compounds which are so objectionable in a gas engine. The smaller portion of it is briquetted with pitch as a binder.

The oils are mixed and sold as wood-preserving material under the name Carbolineum. These tar oils contain mostly hydrocarbons of the aliphatic series, but members of the aromatic series are also present, such as benzol, pyridine bases, and phenols. Formerly the brown coal tars were chemically treated and the industry was quite profitable, especially to the paraffin manufacturers.

Diagram of Bohemian Lignite Tar Treatment.

The commercial products are in bold-faced type.

- TAR
  - Tar water
  - Light oil 392 deg. F. (200 deg. C.)
    - Raw benzol 383 deg. F. (195 deg. C.)
      - **Benzol and its homologues**
      - Phenol
      - **Pyridin**
    - Creosote oil
  - Intermediate oils 455 deg. F. (235. deg. C.)
    - Raw heavy benzol
      - Refined heavy benzol and its homologues
      - Cresols
    - **Gas oil**
    - **Creosote oil**
  - Heavy oils 527 deg. F. (275 deg. C.)
    - Carbolineum
    - Paraffin mass
  - Soft paraffin mass
    - Paraffin oil
    - Paraffin mass
    - Pitch
  - Pitch
    - Soft paraffin mass
      - Soft paraffin
      - Paraffin oil
    - Hard paraffin mass
      - Hard paraffin
      - Paraffin oil
    - Red products
    - Gas
    - Coke

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[1] Lunge and Köhler, "Steinkohlenteer und Ammoniak," 1912, p. 166.

But since brown coal tar oils are known to possess wood-preserving qualities, they are sold undistilled at high prices.

The profit of a lignite distillation plant in Bohemia, per ton of lignite coke, is shown in the following schedule.

For 1 ton (2,000 lbs.) are needed 2.32 tons of raw lignite, at $0.97 per ton		$2.25
Running expenses, amortisation, and general management		.88
Total		$3.13
Profit on by-products	$0.73	
Profit on electric power	.24	
Total	$0.97	0.97
Cost, per ton		$2.16

Thus one ton of lignite coke costs $2.16. Since the selling price is $2.75, there is a profit of 59 cents per ton. A plant working up 100,000 tons of raw lignite annually, produces 43,000 tons of lignite coke, and gives a profit of $25,000. The necessary capital amounts to $170,000, which gives a profit of almost 15 per cent on the investment. The by-products and surplus gas represent 45 per cent of the expense of lignite coke.

Only a general idea of the profitableness of the lignite distillation in Saxon-Thuringen and of the bituminous shale in Scotland can be obtained. The Germans publish no reports on their industry and the English give only general data.

The plants of Saxon-Thuringen pay 12 per cent dividend. One plant with a capital of $750,000 works up 510,000 tons of lignite annually, and shows a profit of $90,000, which corresponds to a profit of 17.65 cents per ton of raw lignite. It must be remembered that the amortisation rate is high in Germany in order to reduce the profit because of the occupation tax, personal tax and income tax.

According to Beilby, the results of Scotch shale distillation give the following:[1]

Cost per ton—cents		Yield per ton—	Cents.
Shale	96	Burning oil, 8.4 gal. at 6. 82 cents	57.28
Retorting	44	Lubricating oil, 3.4 gal. at 6.38 cents	21.69
Refining	28	Paraffin wax, 3.0 gal. at 28.00 cents	84.00
		Ammonium sulphate, 60 lbs. at 1.00 cent	60.00
Total	168		
		Total	224.00
		Less	168 00
		Gross profit	56 00

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[1] J'l Soc. Chem. Ind., 1897, p. 886.

The profitableness of the Scotch shale industry represented by the four leading plants is seen from the following table. The amounts given are in pounds Sterling.[3]

TABLE XV.

Name.	Obligations in bonds.	Preferred stock.	Original stock.	Dividends and profits.			
				1908.	1909.	1910.	1911.
				Per cent.		Per cent.	
1. Brasburn	55,350	100,000	149,750	17.5	10.0	21.09	23.33
2. Oakbank	50,000	100,000	170,000	15.0	10.0	30.21	27.22
3. Pumpherstone	41,750	100,000	110,500	50.0	50.0	62.89	69.00
4. Tarbras	15,900	50,000	85,000	15.0	7.5	13.89	14.49

Amount of profit carried forward--pounds Sterling:

Name.	1911.	1912.
1. Brasburn	6,603	747
2. Oakbank	4,255	5,783
3. Pumpherstone	12,021	12,598
4. Tarbras	1,648	3,895

In 1911, Germany produced:

	Tons
Bituminous coal	160,742,272
Brown coal	73,516,789
Briquettes	16,836,679

One ton of briquettes requires 1.75 tons raw lignite as material and 0.88 tons as fuel, total 2.63. The 16,836,679 tons of briquettes mentioned above required for their manufacture 44,280,000 tons of lignite. The distillation plants of Saxon-Thuringen used 1,575,000 tons. The total amount of lignite treated then was 45,855,000 tons, or 62.4 per cent of the entire lignite production.

Notwithstanding the fact that the more concentrated fuels, English and Westphalian coal and anthracite, are marketed in Germany, lignite mining continues to flourish. But the lignite, in order to compete successfully with the other coals, must be put into a concentrated form, or, as is done in Saxon-Thuringen, the lignite must be treated chemically.

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[3] Petroleum World, 1912, p. 247.

CHAPTER XI.

DISTILLATION OF A TEXAS LIGNITE, FOR RECOVERY OF BY-PRODUCTS.

In order to determine the quantity and nature of the by-products to be obtained from the destructive distillation of lignite, a sample was secured from the Texas Coal Company, Rockdale, Milam county. The composition of this lignite was as follows:

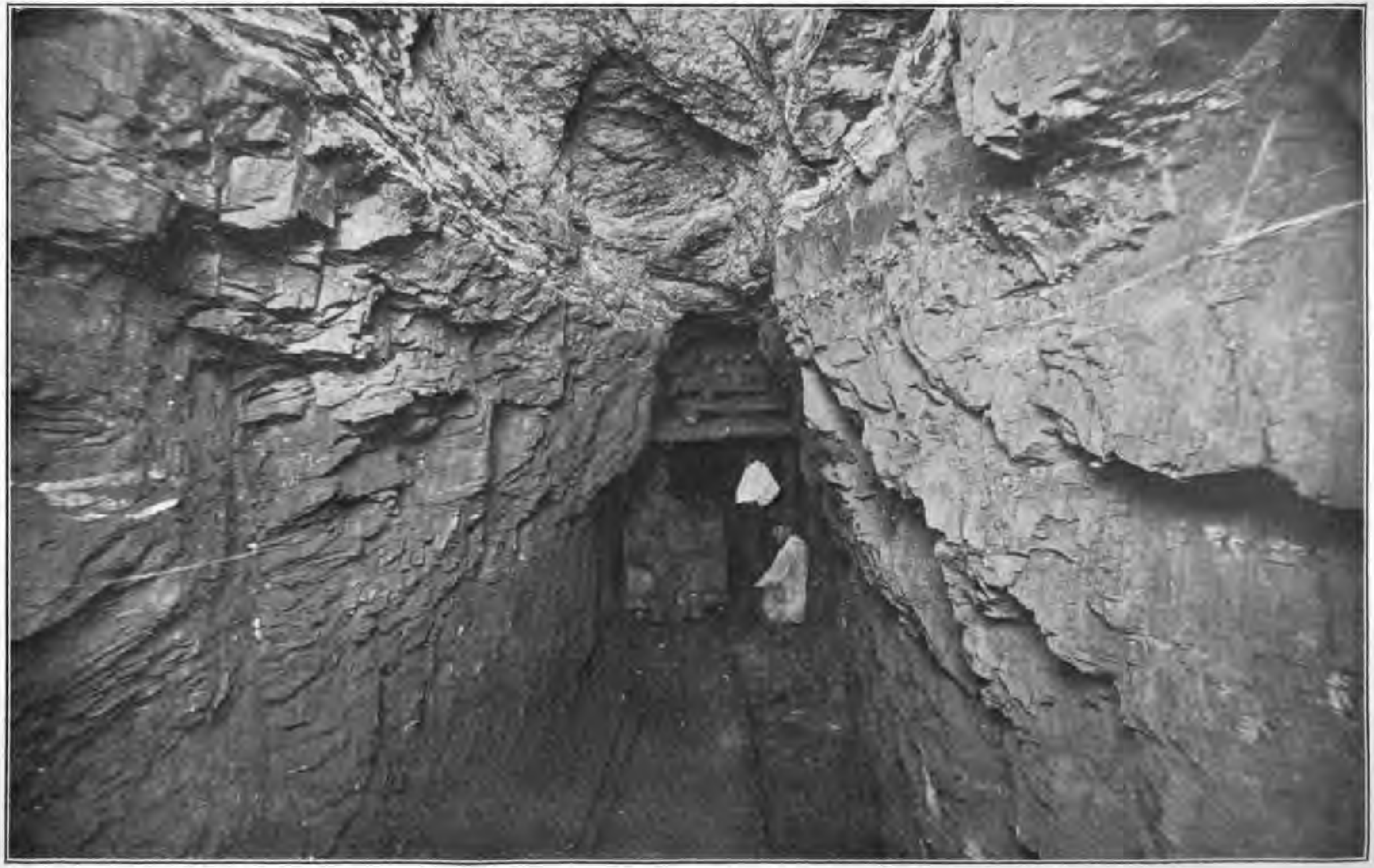
Composition.	Per cent.	
	As rec'd.	Dry.
Moisture	29.83	....
Volatile combustible matter	35.46	50.50
Fixed carbon	27.03	38.50
Ash	7.98	11.00
Sulphur	0.88	1.25
Nitrogen	1.78	2.53

The distillation was made in a cast iron vertical retort, placed in the furnace and covered over with coke, which was kept burning with a gasoline burner as needed. The products from the distillation were led into a water-cooled condenser, then into a wash-bottle, then into dilute sulphuric acid, and then through a tower filled with absorbent cotton. The gas was stored in a large tank.

At first the heat was applied slowly. In about twenty minutes steam appeared in the condenser, and in thirty minutes, a yellowish gas (tar vapor). During the first hour of distillation, about 14 per cent of the total gases passed over, and the distillation was completed in about 2½ hours. The yield of gas was disregarded, since the amount, heating power, candle-power, etc., had been already determined.

The results of four separate determinations are given below, in percentages.

Amount of.	I.	II.	III.	IV.
Residue from lignite, as charged	38.81	40.60	41.90	40.70
Residue from dry lignite	55.44	56.38	56.62	55.75
Ammoniacal liquor	36.10	34.00	33.00	34.30
Total ammonia in raw lignite	0.85	0.63	0.84	0.71
Tar, raw lignite	6.90	7.40	7.87	10.10
Tar, dry basis	9.86	10.28	11.04	13.83



Texas Coal Co. (Lignite) Rockdale Milam County. A tunnel in lignite.

The composition of the residue was as follows:

	I.	II.	III.	IV.
Moisture	0.95	0.93	1.00	1.00
Volatile combustible matter	2.27	6.64	2.77	4.85
Fixed carbon	75.28	76.68	73.66	72.17
Ash	21.50	15.75	22.57	21.98
	100.00	100.00	100.00	100.00
Sulphur	1.54	1.45	1.48	1.36
B. t. u., per pound	10,708	11,287	10,224	10,462

It will be noticed that the ash content of I, III, and IV, is about the same. Residue No. II had only 15.75 per cent of ash, but in this particular case the lignite carried 8 per cent of ash. It will be noticed, also, that the volatile matter in Residue No. II is 6.64 per cent, showing that the heating was not carried far enough. The yield of ammonia in this case was also less, since the ammonia compounds require a high heat to break them up, and they are among the last products to come off.

During the distillation, about 10 per cent of the lignite crumbled into dust. Lignite residue is dark gray in color, glossy, slightly porous, hard, and has a clear metallic ring. There was no agglomeration of the particles and no coking. The residue burns without flame or smoke, and has an average heating power of 10,500 B. t. u. per pound.

The yield of tar, as well as the nature of it, appears to depend on a variety of circumstances, such as the water contained in the raw material; the pressure in the distillation space; the size of the distillation apparatus; the surface of the walls of the apparatus; the rapidity of the suction of the gases; the temperature of the distillation, especially at the end of the process; hence it is not possible to duplicate conditions very closely, especially when one considers, also, the variation in the raw material itself.

Tar.

The tar has a specific gravity of 0.865 at 72 degrees F. It clogs at 60 degrees F. and is of butter-like consistency at 50 degrees F. The color is dark brown and the free carbon content (dust, residue, etc.) is 1.3 per cent.

It was examined by fractional distillation for its content of oils, by "cracking" for the content of paraffin, and by washing with alkali and acid for acid and basic content. Since the tar of Texas lignite seems to occupy a position between the tar of bituminous coals and that of pyropissit, and since, therefore, aromatic as well as aliphatic substances are to be expected, the phenols and pyridine bases of the first series must be separated from the paraffins of the other.

The tar from Texas lignites was distilled into four fractions. The residue of pitch was "cracked". The oils, paraffin masses, acid and basic substances, and then paraffin were determined.

The results were as follows:

Fraction.	Per cent.
Water	0.40
1st fraction, to 392 deg. F., light oil	6.81
2nd fraction, to 527 deg. F., middle oil	17.95
3rd fraction, to 600 deg. F., heavy oil	28.75
4th fraction, to 660 deg. F., soft paraffin oil	12.00
Residue, soft pitch	32.57
When "cracked" the pitch gave the following:	
Hard paraffin mass	19.01
Red products	1.30
Coke	11.00
Gas and loss	1.26
Total	32.57

Distillation of Tar.

		Per cent.
I.	Fraction, light oils, specific gravity 0.830	....
	Active phenol content	19.51
	Bases	3.20
II.	Fraction, intermediate oils, specific gravity 0.983	....
	Active phenol content	27.50
	Bases	6.00
III.	Fraction, heavy oils, specific gravity 0.951	....
	Active phenol content	20.90
	Bases	3.00
IV.	Fraction, soft paraffin oil, specific gravity 0.951	....
	Active phenol content	24.00
	Bases	3.00
V.	Fraction, hard paraffin oil, specific gravity 0.921	....
	Active phenol content	18.00
	Bases	3.00

The coke contained 7 per cent of volatile combustible matter.

Paraffin estimation in the acid and base free oils:

In the heavy oils	4.28 per cent., melting point	122 deg. F.
In the soft paraffin oils	12.37 per cent., melting point	129 deg. F.
In the hard paraffin oils	12.43 per cent., melting point	138 deg. F.

Total Paraffin from Raw Tar.

	Per cent.		
	Heavy oils.	Soft paraffin oils.	Hard parafin oils.
Yield of oils	28.75	12.00	19.00
Loss by washing to remove acids and bases	24.00	27.00	21.00
Remainder after washing	21.85	8.76	15.00
Paraffin content of washed residue	4.30	12.40	12.50
Melting point, Centigrade	50 deg.	54 deg.	59 deg.
Melting point, Fahrenheit	122 deg.	129 deg.	138 deg.

Total paraffin in tar .... 3.88 per ccent

As the congealing points show, these are only the hard paraffins. As a matter of fact, the tar contains about 8 per cent of paraffin.

From a technical standpoint, three forms of ammonia may be obtained: 1. So-called "free" ammonia, which can be driven off from ammonia water and wash water, but it is doubtful if there is any free ammonia in such gases as we are now dealing with. 2. Combined ammonia which can be made volatile by adding an alkali earth. 3. Ammonia which can be taken up completely by sulphuric acid only.

In order to determine how much nitrogen contained in lignite is changed into ammonia, the third distillate above was taken as a basis. The nitrogen content was as follows:

Nitrogen content.	Per cent.
In dry lignite	2.53
In tar	2.82
In the residue	0.18
In the gas	4.90

Another way of stating this is as follows:

1,000 parts of raw lignite with 26 per cent of water, gives 18.72 parts of nitrogen; 419 parts of residue, 78.4 parts of tar, and 330 parts of water. The yield of gas in cubic feet per net ton is 7,500. On this basis, a net ton, 2,000 pounds, of raw lignite would contain as follows:

Compound.	Pounds.
Nitrogen, calculated as ammonia	45.36
Residue	838
Tar	156.8
Water	660
Gas	300

The nitrogen compound in the condensed water may consist of cyanogen compounds and members of the pyridine and chinolin groups. Of these compounds, 3.98 per cent are in the coke, 6.46 per cent in the tar, 9.30 per cent are in the ammonia, 45.50 per cent are in the gas, and 34.76 per cent are unaccounted for.

The distribution of the nitrogen is quite different from that of other bituminous materials subjected to dry distillation. In the Scotch shales, 75 per cent of the nitrogen is changed to ammonia by the use of steam, but in this case the carbon of the residue would be consumed.

Watson Smith[1] found nitrogen in:

	Per cent.
Ordinary gas coke	1.37
Bee-hive coke–	0.53
Simon-Carves coke	0.38

A. Hennin[2] is of the opinion that ammonia is found in coal only in minute amounts, but that it is formed as soon as the coal has risen to a temperature of 1,800 degrees F. (1,000 degrees C.). Higher temperatures than this do not seem favorable to its formation, while at a temperature below red heat, the formation of ammonia ceases.

In the Texas lignite which was investigated, about 10 per cent of the nitrogen is changed to ammonia; while in the Saxony bituminous coal only 6.4 per cent is changed, and in some English coal, 10.8 per cent.

In treating the brown coal in vertical ovens in Saxony, the heating of the material is more gradual than in the horizontal ovens and the operation of carbonizing can be divided into three definite zones. The first is the uppermost and coolest zone, and may be called the drainage zone, for the steam escapes with little or no tar, or ammonia. The second zone is that of the formation of gas and tar, with some ammonia. The third zone is the zone of the highest heat, and completes the distillation with the formation of ammonia.

In order to test the separation of the water from the ammonia, a distillation was made in which the first portion of water that came over was separated from the remainder, then another portion was separated, and the gas washed in the remainder of the water. The lignite treated contained 28 per cent of moisture. The water contained ammonia as follows:

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[1] J'l Chem. Soc., 43, p. 105.

[2] J'l Gas Lighting, 1892, p. 296.

	Per cent.
1st portion	0.013
2nd portion	0.042
3rd portion	0.990

The amount of water to be treated can thus be reduced one-half, and the ammonia can be recovered in a column still, and the gas passed into 60 degrees B. sulphuric acid, for the manufacture of ammonium sulphate. The gases formed during carbonization can be used to heat the oven, and, according to European practice, there is an excess of 40 per cent to be thus used, or sent to gas engines.

There could be recovered from a ton of ordinary Rockdale lignite carrying 26 per cent of moisture and 9 per cent of ash, the following:

Residue	800 pounds
Tar	156 pounds—16.17 gals.
Sulphate of ammonia	18 pounds
Surplus gas	3,000 cu. ft.

The following calculation of the value of these separate products is made with the distinct understanding that local conditions will often affect the result seriously.

The value of the residue can be calculated in two ways, as an industrial fuel, and as a household fuel. As an industrial fuel it can be used in the form in which it comes from the retorts or ovens without any preparation. Its value would depend on the local price of fuels with which it would compete. In San Antonio, for instance, Rockdale lignite and Beaumont oil are used as fuels, among others. The price of lignite is $1.69 per ton, and it has a heat value of 7,500 B. t. u. per pound. On account of the high content of moisture, we will allow that only 50 per cent heat effect can be obtained. The heating power of the Beaumont oil may be taken at 19,000 with a heat effect of 78 per cent.

To determine the relative value of lignite, crude oil, and lignite residue for steaming purposes, the following calculation is made; with an allowance of 50 per cent heat efficiency for the lignite, 78 per cent for the oil, and 72 per cent for the lignite residue.

If we allow that the value of the lignite residue is $3.00 per ton, and that it has 11,134 B. t. u. per pound, the price per hundred pounds is 15 cents. To generate 100 pounds of normal steam requires 1,150 B. t. u.

Lignite.

$$\frac{7500 \text{ B. t. u. x } 50}{1150} = 3.26 \text{ pounds normal steam.}$$

100 pounds lignite costs 8.25 cents=3.26 pounds normal steam, and we have then 100 pounds normal steam costs 2.53 cents.

Fuel Oil.

$$\frac{19,000 \text{ B. t. u. x } 78}{1150} = 12.88 \text{ pounds normal steam per pound of oil.}$$

1 barrel, 42 gals., costing $1.20, will give a cost per hundred pounds of 37½ cents. As 100 pounds of oil will give 1,288 pounds of normal steam for 37½ cents, we have the cost of 100 pounds of normal steam, 2.91 cents.

Lignite Residue.

$$\frac{11,134 \text{ x } 72}{1150} = 6.97 \text{ pounds of normal steam.}$$

At $3.00 per ton, 100 pounds costs 15 cents, or 697 pounds of normal steam, costs 15 cents; and 100 pounds of normal steam would cost 2.15 cents.

The 800 pounds of residue obtained would be worth $1.20, for fuel purposes.

Tar.

The 156 pounds (16.17 gallons) of tar recoverable from the ton of lignite could be used for the manufacture of heavy oils, soft paraffin oils and hard paraffin oils. After removing the acids and bases by washing, there would remain in the washed tar 21.85 per cent of heavy oils, 8.76 per cent of soft paraffin oils, and 15 per cent of hard paraffin oils. The total hard paraffin in the tar is probably about 3.88 per cent, the total paraffin being about 8 per cent.

After these oils are distilled from the tar, there remain 32.57

per cent of soft pitch and, as already stated, when "cracked" the pitch gave the following:

	Per cent.
Hard paraffin mass	19.01
Red products	1.30
Residue	11.00
Gas and loss	1.26

There was of paraffin, in the acid and base free oils, as follows:

	Per cent.
In the heavy oils	4.28
In the soft paraffin oils	12.37
In the hard paraffin oils	12.43

The valuation of tar is a highly technical matter, and we do not propose at this time to enter upon it, except to point out the products obtainable by distillation.

In a briquetting plant, both the soft and the hard pitch could be used as a binding material.

Sulphate of Ammonia.

There could be recovered from a ton of lignite 18 pounds of sulphate of ammonia, worth, at 3 cents a pound, 54 cents.

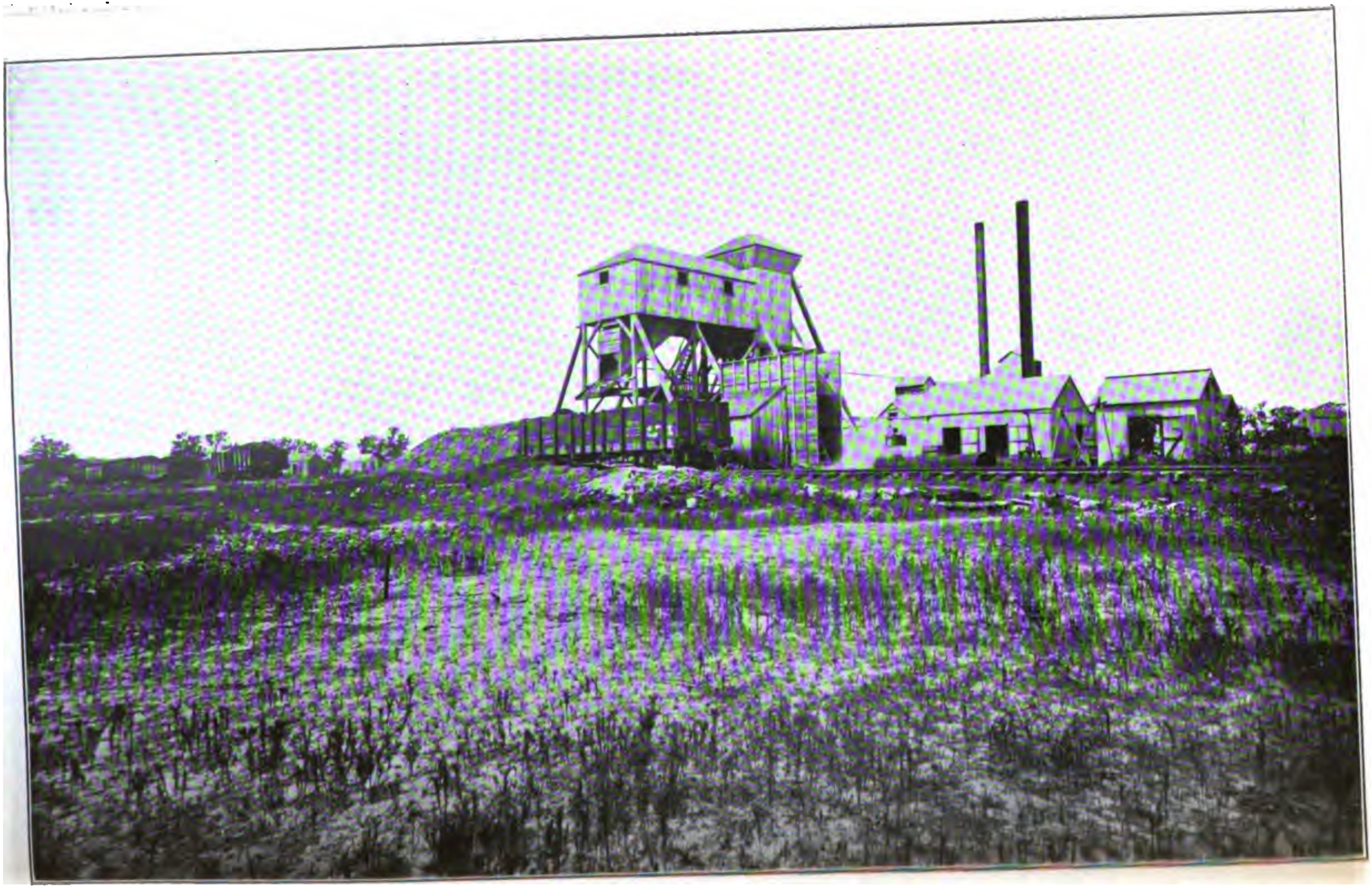
Surplus Gas.

The surplus gas would be 3,000 cubic feet, and we think it should be worth 30 cents per thousand cubic feet at the works; a total value of 90 cents.

The following statement, therefore, includes the value of the by-products to be obtained from a ton of lignite:

	Value.
Residue from retorts, 800 pounds, at $3.00 a ton	$1.20
16 gals. of tar, at 5 cents	80
18 pounds sulphate of ammonia, at 3 cents	54
3000 cubic feet surplus gas, at 30 cents	90
	$3.44

In order to arrive at an approximation of the value of the surplus gas when used to generate power in a gas engine, the following calculation may be used: to guarantee 1 horse-power in an economically working gas motor, 10,700 B. t. u. are necessary. One cubic foot of this gas has 387 B. t. u. and 28 cubic feet are required for 1 horse-power hour, or 1,000 cubic feet are equivalent to 35.7 horse-power hours. The 3,000 cubic feet of surplus gas from the ton of lignite will generate 107 horse-power hours, and the cost is about 1 cent per horse-power hour.



Texas Coal Co. (Lignite), Rockdale, Milam County.

CHAPTER XII.

DRY DISTILLATION OF TEXAS LIGNITES.*

In order to study lignites with reference to the amount and quality of the gas and solid residue to be obtained from them by dry distillation we selected 22 typical lignites from different parts of the State.

The methods used have already been described in Chapter IV, relating to the dry distillation of coals. In Chapter XI we gave the results of the detailed examination of a sample of Rockdale lignite for all of the recoverable products, but in this chapter we consider merely the gas and solid residue.

Tables XVI and XVII give the results obtained.

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*In the Second Annual Report, Texas Geol. Sur., 1890, pp. 38-52, there is an article by Dr. Otto Lerch on "Lignites and Their Utilization with Special Reference to the Texas Brown Coals." This paper describes, to a certain extent, the condition of the industry in Germany at that time. For information as to present methods, etc., the reader is referred to Chapter X of this Bulletin, prepared by Dr. W. Bredlick.

TABLE XVI.

Results of Distillation Tests on Texas Lignites. Analyses by S. H. Worrell.

Analysis No.	Yield of gas, cubic feet per net ton dry lignite.	Gas—Dry.									Lignite—Dry.								
		Composition.					Specific Gravity.	Candle Power.	B. t. u. per cubic foot.		Proximate analysis.				Ultimate analysis.				B. t. u. per Pound.
		Illuminants.	Carbon Monoxide.	Hydrogen.	Methane.	Nitrogen.			Calc.	Obs.	Volatile combustible matter.	Fixed Carbon.	Ash.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	
667	6,149	1.6	15.4	46.4	25.4	8.8	.458	—1.	492	489	48.10	41.05	10.85	0.80	56.00	4.35	26.48	1.54	10,220
361	9,755	1.8	9.8	56.2	24.4	7.4	.368	—1.	494	496	55.70	30.09	14.31	0.78	53.80	4.18	24.95	2.08	8,979
328	8,157	1.7	2.6	49.3	41.6	5.5	.353	—1.	538	569	59.50	31.71	8.75	1.00	62.77	4.11	21.14	2.23	9,855
368	5,358	2.1	11.2	48.7	32.6	5.4	.400	4.	574	564	55.00	31.91	13.00	1.33	58.42	4.96	20.00	2.20	10,510
329	6,240	2.3	11.3	46.2	32.7	7.5	.423	—1.	550	570	44.80	33.89	21.31	0.97	55.69	4.75	15.57	1.71	9,244
668	7,996	1.8	11.8	51.2	20.6	8.0	.457	—1.	518	560	44.70	42.63	12.67	0.64	57.06	4.40	23.70	1.53	10,600
327	6,329	1.5	3.8	46.8	33.3	14.6	.409	2.5	580	560	52.14	38.22	9.64	0.81	61.14	4.75	21.95	1.71	10,510
671	6,058	2.0	17.2	48.0	23.4	9.0	.446	—1.	494	489	46.18	43.63	10.20	0.68	54.70	3.15	29.13	2.14	10,840
429	9,560	4.6	19.4	50.4	19.4	6.2	.537	3.	558	513	58.60	30.64	10.76	1.05	57.77	4.70	23.74	1.98	9,782
616	6,685	1.0	15.5	46.8	28.7	7.0	.465	2.	520	513	56.18	37.20	6.62	0.65	61.42	5.12	24.63	1.56	10,540
430	9,028	2.1	8.0	44.2	31.2	11.6	.454	9.3	544	525	52.90	33.99	13.11	0.80	57.20	5.36	21.67	1.86	10,120
354	6,500	2.1	11.5	52.5	29.4	4.5	.326	1.5	533	575	45.00	43.00	12.00	1.40	n. d.	n. d.	n. d.	n. d.	10,980
499	8,135	2.5	9.0	46.4	30.0	10.0	.474	3.4	524	519	50.76	39.54	9.70	0.90	60.72	5.03	21.92	1.73	10,226
517	9,140	1.4	14.0	55.0	22.2	6.8	.373	—1.	450	466	48.54	37.65	13.81	1.00	59.58	4.29	20.09	1.33	9,700
519	6,435	2.2	21.9	44.2	19.7	10.8	.492	—1.	458	458	49.28	32.90	17.82	1.34	56.67	4.70	18.14	1.33	9,709
670	5,576	4.8	22.6	41.4	23.4	7.0	.449	6.	533	540	51.20	38.78	10.02	0.72	64.20	4.56	19.30	1.20	11,182
669	6,195	2.0	17.0	50.0	23.8	6.2	.427	1.	512	498	43.38	41.43	15.19	0.54	57.42	4.03	20.48	2.34	10,900
597	8,751	1.5	20.0	51.0	23.3	0.8	.437	1.5	510	496	47.60	41.31	11.09	0.98	61.20	4.06	20.58	2.09	10,030
576	8,842	1.8	21.6	47.8	15.9	7.7	.503	—1.	425	422	49.00	44.00	7.00	0.87	60.47	4.78	25.20	1.70	9,957
590	9,118	1.6	16.6	50.2	28.1	3.5	.372	1.	539	534	47.00	40.71	11.49	1.29	57.82	4.63	23.09	1.68	10,030
630	7,352	2.0	19.4	43.8	24.6	8.7	.468	3.	485	498	45.66	41.12	13.22	0.80	58.81	4.46	20.21	2.50	10,410
601	9,217	0.8	17.9	46.2	20.5	5.0	.514	—1.	460	440	50.52	39.20	10.28	1.20	59.16	3.82	22.96	2.58	9,855
Average	7,571	2.2	14.4	48.3	25.1	7.5	.436	1.2	513	549	50.51	37.55	11.94	0.93	58.66	4.48	22.14	1.85	10,200

The key to Table XVI is as follows:

No. 667. Alba-Malakoff Lignite Co., Alba, Wood county.
No. 361. American Lignite Briquette Co., Big Lump, Milam county.
No. 328. Bear Grass Coal Co., Jewett, Leon county.
No. 368. Bertetti Coal Co., Lytle, Medina county.
No. 329. Carr Wood & Coal Co., Lytle, Medina county.
No. 668. Como Lignite Co., Como, Hopkins county.
No. 327. Consumers Lignite Co., Hoyt, Wood county.
No. 429. Cookville Coal & Lumber Co., Mt. Pleasant, Titus county.
No. 616. Edgewood Coal & Fuel Co., Edgewood, Van Zandt county.
No. 430. Houston County Coal & Manufacturing Co., Crockett, Houston county.
No. 354. Houston County Coal & Manufacturing Co., Evansville, Leon county.
No. 499. Independence Mining Co., Phelan, Bastrop county.
No. 517. Lone Star Lignite Mining Co., Como, Hopkins county.
No. 519. *Melcher Coal & Clay Co., O'Quinn, Fayette county,
No. 670. Rockdale Coal Co., Hicks, Lee county.
No. 669. Rockdale Consolidated Coal Co., Rockdale, Milam county.
No. 597. Rockdale Lignite Co., Rockdale, Milam county.
No. 576. Rowlett & Wells, Rockdale, Milam county.
No. 590. Southwestern Fuel Co. (formerly Southwestern Fuel & Mfg. Co.), Calvert, Robertson county.
No. 630. Texas Coal Co., Rockdale, Milam county.
No. 601. Vogel Coal and Manufacturing Co., Rockdale, Milam county.

This key applies also to Table XVII. The other figures in that table, under head of Analysis No. —, refer to our current laboratory numbers.

There are 8 principal things to be observed from a study of Table XVI:

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*This lignite is not mined.

1. The yield of gas per net ton of dry lignite varied from 5,358 to 9,755 cubic feet, the general average being 7,591 cubic feet.

2. The candle-power of the gas was low, only two samples giving as much a 6 candle-power, one of these giving 9.3 candle-power.

3. The B. t. u. per cubic foot varied from 425 to 580, the general average being 513.

4. A high yield of gas seemed to be accompanied by a tendency towards a lower heating value in the gas, but the differences were not especially noteworthy. Thus:

When the yield of gas was:

Cubic feet.	The B. t. u. per cubic foot ranged	With an average of
From 5,000 to 6,000	from 533 to 574	553
From 6,000 to 7,000	from 494 to 580	517
From 7,000 to 8,000	from 485 to 518	501
From 8,000 to 9,000	from 425 to 538	499
From 9,000 to 10,000	from 450 to 558	507

5. With respect to the composition of the gas, the following variations and averages were observed:

	From.	To.	Average.
Illuminants	0.8	4.8	2.2
Carbon monoxide	2.6	22.6	14.4
Hydrogen	41.4	56.2	48.3
Methane	15.9	41.6	25.1

6. With respect to the composition of the dry lignites the following variations and averages are to be observed:

	From.	To.	Average.
Volatile combustible matter	43.38	59.50	50.51
Fixed carbon	30.09	44.00	37.55
Ash	6.62	21.31	11.94
Sulphur	0.54	1.40	0.93
Carbon	53.80	64.20	58.66
Hydrogen	3.15	5.36	4.48
Oxygen	15.57	29.13	22.14
Nitrogen	1.20	2.58	1.85
British thermal units, per pound	8,979	11,182	10,200

7. When the volatile combustible matter was:

Per cent.	The yield of gas in cubic feet per ton was	Average.	The B. t. u. in the gas were from	Average.
From 40 to 45	from 6195 to 7996	6810	512 to 550	526
From 45 to 50	from 6058 to 9140	7594	425 to 539	487
From 50 to 55	from 5576 to 9217	7637	460 to 580	528
From 55 to 60	from 5358 to 9755	7903	494 to 574	537

8. The most noteworthy circumstance in connection with Table XVI is that from lignites of extreme variation in composition, it is possible to secure, on the average, from 6,800 to 7,900 cubic feet of gas per net ton, and this gas carried from 487 to 537 B. t. u. per cubic foot. In heating power, this gas compares favorably with ordinary city gas at 600 B. t. u. per cubic foot. If we allow that good gas coal costs $6.00 a ton, and yields 9,000 cubic feet of 600 B. t. u. gas, we would have 15 cubic feet (=9,000 B. t. u.) for one cent. If we allow that dry lignite costs $2.00 a ton and that it yields 7,500 cubic feet of 500 B. t. u. gas we would have 37.5 cubic feet (=18,750 B. t. u.) for one cent. The raw material cost of coal gas for fuel purposes is twice as great as that of lignite gas.

Table XVII.

Composition and yield of residue left in retort after distilling the lignites represented in Table XVI. Dry.

Analysis No.	Volatile combustible matter	Fixed carbon.	Ash.	Sulphur.	B. t. u. per lb.	Yield of residue, per cent.	With complete removal of volatile combustible matter.			
							Fixed carbon.	Ash.	B. t. u. per lb.	Yield of residue.
667–771....	6.21	76.09	17.70	1.90	11,786	50.00	81.14	18.86	12,566	53.31
361–743....	4.95	74.38	20.67	1.69	11,269	50.00	77.20	22.80	11,855	52.60
328–748....	8.07	77.53	14.40	1.42	12,144	56.20	84.33	15.67	13,210	61.13
368–749....	6.67	71.58	21.75	2.27	11,592	50.00	76.69	23.31	12,420	53.57
329–750....	4.05	68.86	27.09	1.54	9,561	50.00	71.76	28.24	9,964	52.11
668–772....	5.29	70.79	23.92	1.08	10,963	57.00	74.74	25.26	11,575	60.17
327–754....	7.69	74.23	18.08	1.15	11,579	54.70	80.41	19.59	12,543	59.25
429–755....	4.64	71.43	23.93	1.44	11,093	67.50	74.89	25.11	11,632	70.78
616–766....	5.27	79.01	15.72	1.20	12,566	50.00	83.40	16.60	13,265	52.78
430–756....	6.25	71.35	22.40	0.99	10,937	56.00	76.10	23.90	11,666	59.73
354–775....	6.48	74.61	18.91	1.64	11,807	50.00	79.77	20.23	12,491	53.46
499–757....	7.20	75.41	17.39	1.29	11,682	50.00	81.26	18.74	12,588	53.87
517–761....	5.41	71.10	23.49	0.71	10,806	51.00	75.16	24.84	11,423	53.91
519–758....	5.41	65.41	29.18	2.85	10,179	57.30	69.15	30.85	10,761	60.57
670–776....	5.30	69.22	25.48	4.36	11,121	60.00	73.09	26.91	11,743	65.99
669–774....	6.31	71.99	21.70	1.80	11,520	62.50	76.83	23.17	12,295	66.70
597–760....	5.87	74.51	19.62	1.52	11,565	50.00	79.15	20.85	12,286	53.11
576–759....	4.55	74.04	21.41	1.51	11,126	56.20	77.56	22.44	11,656	58.87
590–762....	4.18	75.62	20.20	1.57	11,379	62.50	78.91	21.09	11,875	65.22
630–770....	7.16	71.09	21.75	1.23	11,429	56.00	71.18	28.82	12,310	60.31
601–763....	7.40	73.57	19.03	0.89	11,450	56.20	79.44	20.56	12,364	60.69
Average..	5.92	72.94	22.14	1.62	11,312	54.90	77.52	22.48	12,023	58.35

A study of Table XVII, the key to which appears under Table XVI, shows:

1. The volatile combustible matter was not completely removed. The amount remaining in the residue varied from 4.05 to 8.07 per cent, with an average of 5.92 per cent.

2. The fixed carbon in the residue varied from 65.41 to 79.01 per cent, with an average of 72.94 per cent. With complete removal of the volatile combustible matter, the fixed carbon would vary from 69.15 to 84.33 per cent, with an average of 77.52 per cent.
3. The ash in the residue varied from 14.40 to 29.18 per cent, the average being 22.14 per cent. With complete removal of the volatile combustible matter, the ash would vary from 15.67 to 30.85 per cent, the average being 22.48 per cent.
4. The sulphur in the residue showed a marked increase over that in the dry lignite. Excluding two abnormally high results, the increase was from 1.22 to 2.37 times, with an average of 1.64. In two cases out of twenty-one, the sulphur in the dry lignite was more than it was in the residue. For the most part the sulphur appeared to be as calcium sulphate (gypsum).
5. The B. t. u. per pound varied from 9,561 to 12,566, the average being 11,312. This has an important bearing on the manufacture of briquettes from the residue. For further information on this subject, see Chapters IX and XI. As some of the volatile combustible matter would probably contain certain heat units, it is useless to calculate what the B. t. u. would be in the residue, if this matter were entirely removed. It is, however, not probable that there would be any loss in the heat units in such residue.
6. The yield of solid residue varied from 50.00 to 67.5 per cent, the average being 54.9 per cent. With complete removal of the volatile combustible matter, the yield would vary from 52.11 to 70.78 per cent, the average being 58.35 per cent.

We may assume, for the moment, that in the ordinary practice of distilling lignites in a closed, or practically closed, retort, the residue will contain about 6 per cent of volatile combustible matter; that the yield of this residue, from dry lignite, will be about 55 per cent, and that it will contain from 73 to 75 per cent of fixed carbon. It is not likely that there will be any economy in completely removing the volatile combustible matter, for the purpose will be to discharge the retorts as soon as the B. t. u. in the gas begin to show a markedly less value. Just where this point may be depends on a number of conditions which, for the most part, have not been ascertained. The yield and the nature of the volatile matter distilled from such substances as coal and lignite depend on many factors, some of them of varying moment. The principal ones appear to be as follows: the size of the material; the amount of disposable hydrogen, i. e., the hydrogen that is free to combine with carbon as a hydro-carbon; the rapidity with which the temperature is raised; the length of time during which a uniform temperature is maintained; the maximum temperature within the retort and within the coal itself; the size and temperature of the space into which the gas is conducted; the rapidity with which the gas is removed from the retort; and the depth of the bed of coal which is being distilled. In dealing with coal and lignite, we have to remember that they are substances which, under the influence of heat, are decomposable into a large number of compounds and that the original compounds formed may react among themselves and produce other and, perhaps, more complicated substances. With the chemico-physical side of this matter we have but little to do at present, our main purpose being to call attention to the fact that Texas lignites are capable of yielding, in dry condition, 7,500 cubic feet of gas per net ton and that this gas carried 500 B. t. u. per cubic foot.

Irrespective of the heating value of the solid residue from the retorts, we have in lignite gas a source of cheap and effective energy, whether this energy be used in mere heating effects or converted into electric power through the medium of gas engines and generators. A plant consuming 100 tons of dry lignite a day would produce 750,000 cubic feet of gas that would contain 375,000,000 B. t. u., and leave 55 tons of solid residue containing 1,100,000,000 B. t. u. In Chapter IX, Professor E. J. Babcock, has described a method for the utilization of the solid residue in the manufacture of briquettes, and reference is here made to that Chapter.

CHAPER XIII.

FUEL OIL.

Fuel oil is of two kinds:

1. Crude petroleum, such as Texas crude, Mexican crude, etc.
2. Petroleum from which certain distillates, such as benzine, gasoline, etc., have been removed in the refineries. The demand for these products during the last year has been so active that a good deal of Texas crude that was formerly sold for fuel purposes direct now goes to the refineries for the recovery of the lighter distillates.

There are no statistics bearing on the proportion of these two kinds of fuel oil now used in Texas.[1]

Some contracts may take this matter into consideration, but ordinarily the specifications call for fuel oil of such and such a gravity and of so many B. t. u. per pound without regard to whether the oil is crude or residue from the stills. The oil must be commercially free of sand, sediment and water. Owing to the advent of Mexican crude in our markets, this oil having a gravity of 0.934 to 0.942, attention will have to be given to the kind of pumps supplying the oil to the burners. The viscosity of this oil is below that of some of the other fuel oils now being used, and it is pumped with more difficulty.

According to the Fuel Oil Journal, Houston, February, 1913, the consumption of fuel oil by Southwestern railroads during the year 1912, was as follows, in barrels of 42 gallons:

System.	Barrels.
Southern Pacific (Texas and Louisiana)	3,924,403
Santa Fe (Texas lines)	2,000,000
Frisco main lines (Texas and Louisiana)	1,630,222
Kansas City Southern (all lines)	1,254,668
All others	700,000
	9,509,293

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[1] In 1904 there were manufactured in the United States 7,209,428 barrels of fuel oil of 50 gallons and in 1909 34,034,577 barrels.

If we allow that, on the average, four barrels of fuel oil are equivalent to one ton of ordinary bituminous coal, this quantity of oil would replace 2,377,323 tons of coal. This is, perhaps, a generous allowance, so if we allow 3½ barrels as equivalent to a ton of coal we have a replacement of 2,716,941 tons of coal, an amount considerably more than the entire coal and lignite production of Texas during that year.

We do not know what the average price of this oil was, but it is not likely that it was less than 85 cents a barrel. The authority just quoted gives the prices of fuel oil at different points in the State during the year 1912, as follows:

	Cents.
Houston	87.
Humble	84.3
Port Arthur	85.7
Sabine	85.7
Fort Worth Corsicana Dallas	91.8

The consumption of fuel oil by the railroads of the United States from 1906 to 1912, inclusive, was about as follows, in barrels of 42 gallons (David T. Day):

	Barrels.
1906	15,577,677
1907	18,849,803
1908	16,870,882
1909	19,905,335
1910	23,817,346
1911	29,748,845
1912	33,605,598

The average number of miles run per barrel of fuel oil consumed varied from 3.93 in 1907, to 3.61 in 1912. While some of the lines involved also used coal the mileage operated by the use of fuel oil was 13.573 in 1907; 15,474 in 1908; 17,676 in 1909; 22,709 in 1910; 30,039 in 1911 and 28,451 in 1912.

The following is taken from an article by Mr. Holland S. Reavis, Editor, Fuel Oil Journal, Houston, published in the Mineral Industry, Vol. XXI, page 641:

"In line with the general advance in crude oil prices, the Texas market strengthened appreciably during the year. In north Texas, the price of light oil at the wells on January 1, 1912, was 55 cents, and heavy oil, 50 cents. On December 31, 1912, light oil was 88 cents, and heavy, 70 cents. Contracts were made January 1, 1912, in the coastal fields for periods of 12 to 18 months at 72 and 72½ cents per barrel for heavy oil at the wells. Some of these contracts were renewed January 1, 1913, at $1.00 to $1.07⅛ per barrel at the wells. South Texas crude oil sold on January 1, 1912, at 70 cents per barrel, on board cars, for fuel use. A year later the price was $1.10 to $1.20 per barrel, on board cars.

"Pipe-line construction in Texas during 1912 was as follows: An 8-inch line, 449 miles long, was laid by the Magnolia Petroleum Company between Electra and Beaumont, connecting at the latter point with the same company's lines leading to deep water at Sabine, on the Gulf coast. Through the new line the Magnolia Company supplies crude to its refineries at Corsicana, about midway between Electra and the terminus, and at Beaumont. There are five stations, the distances between them being as follows: Electra to Alvord, 94 miles; Alvord to Corsicana, 117 miles; Corsicana to Richards, 120 miles; Richards to Beaumont, 118 miles. De La Vergne crude oil engines furnish the power at the stations for pumping the oil. The line traverses the various oil fields of north Texas.

"The Gulf Pipe Line Company constructed a 6-inch branch line from its main 8-inch Oklahoma-Texas trunk line at Saltillo to Fort Worth, a distance of 136 miles, for the purpose of furnishing crude to the Gulf Refining Company's new refinery at Fort Worth, which was completed and placed in operation in the spring of 1912. The Pierce-Fordyce Oil Association completed a refinery at Fort Worth in the spring of 1912, obtaining its crude supply by tank cars from Electra and Oklahoma, and also receiving oil from the pipe-line of another company, which passes through Fort Worth. The Texas Company constructed an 8-inch pipe-line from the north Texas oil fields to Dallas, by way of Fort Worth."

List of Refineries in Texas.

Name.	Location.	Daily capacity, barrels.
Pierce-Fordyce Oil Association	**Texas City**	**2,000**
Pierce-Fordyce Oil Association	**Fort Worth**	**2,000**
Gulf Refining Company	**Port Arthur**	**30,000**
Gulf Refining Company	**Fort Worth**	**5,000**
Magnolia Petroleum Company	**Beaumont**	**20,000**
Magnolia Petroleum Company	**Corsicana**	**3,000**
Texas Company	**Port Arthur**	**18,000**

Name.	Location.	Daily capacity, barrels.
Texas Company	Gates	15,000
Texas Company	Port Arthur	3,000
United Refinery Company	Beaumont	1,500
Webster Refining Company	Orange	500
Total		100,000

So far as we are aware, there are no statistics relating to the consumption of fuel oil by industrial establishments, hospitals, hotels, etc., but this quantity may be taken, we think, at a million barrels a year, with a tendency towards a lesser quantity, owing to the increasing price of oil.

During the first six months of 1913, average current quotations were as follows, per barrel of 42 gallons:

	Per barrel.
Houston	$1.22
Humble	1.125
Port Arthur	1.20
Sabine	1.20
Fort Worth Corsicana Dallas	1.191

Comparing these prices with those that maintained during the year 1912 it will be seen that the price of fuel oil at Houston increased from an average of 87 cents to $1.22; at Humble, from 84.3 cents to $1.125; at Port Arthur and Sabine, from 85.7 cents to $1.20; at Fort Worth, Corsicana and Dallas, from 91.8 cents to $1.191. In the early part of November, 1913, the price of Mexican crude, delivered to Gulf ports, varied from $1.00 to $1.20.

We have made in our own laboratory, a number of analyses of fuel oils. Between November 26, 1912, and June 3, 1913, we examined 19 samples for the State Purchasing Agent, Austin, of fuel oil delivered to the different State institutions for which he secured supplies. The specific gravity varied from 0.868 to 0.931, with an average of 0.90; the B. t. u. per pound varied from 18,964 to 19,500, with an average of 19,211. We examined 12 samples for flash point, and found the variation to be from 110 to 218 degrees F., with an average of 151 degrees F. We examined 10 samples for burning point and found the same to vary from 180 to

276 degrees F., with an average of 221 degrees F.[1] These samples were all commercially free from sand, sediment and water.

We have examined one sample of Mexican crude, used for fuel purposes. The color was black; specific gravity, 0.938; viscosity, 3,600 at 70 degrees F.; flash point, 140 degrees F.; burning point, 185 degrees F.; heating power, 19,232 B. t. u. per pound.

Mexican Crude Oil.

According to the Fuel Oil Journal, Houston, the production of crude petroleum in Mexico from 1907 to 1912, inclusive, was as follows, in barrels of 42 gallons:

	Barrels.		Barrels.
1907	1,000,000	1911	14,051,643
1908	3,481,410	1912	16,500,000
1909	2,488,742		
1910	3,332,807	Total	40,854,620

The importation of Mexican crude oil into Texas ports for this year, up to the 20th of June, was as follows, by districts:

	Barrels.	Total value.	Value per bbl., cents.
Sabine and Port Arthur	2,164,523	1,202,690	55.56
Galveston	1,273,599	718,687	58.00
Port Aransas	96,566	55,731	58.00
Total	3,534,688	1,977,108	

Heat Values in Mexican Crude.[2]

"Samples of Mexican crude oil taken from 8 cargoes shipped from Tuxpan and Tampico showed heat values as follows:

Specific gravity.	B. t. u., per pound.
0.942	19,620
0.941	19,638
0.937	19,170
0.937	19,170
0.937	19,224
0.936	19,476
0.935	19,440
0.934	19,620
Average........0.937	19,420

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[1] In the British mercantile marine the minimum flash point for fuel oils is 150 deg. F. (Abel test), and in the navy 200 deg. F. In the United States the standard flash point is 140 deg. F. (Abel-Pensky or Pensky-Martens test). In Russia, Roumania and Germany it is 176 deg. F. (Boverton Redwood, Treatise on Petroleum, 3d Ed., 1913, p. 381.)

[2] Fuel Oil Journal, Vol. 4, No. 1, July, 1913, page 32.

The magnitude of the oil carrying trade, in steam and sailing vessels, is shown by the following statistics taken from Boverton Redwood's "Treatise on Petroleum," 3d edition, 1913:

Of tank steamers, he gives a list of 363, with a net tonnage varying from diminutive steamers of 37 tons, such as the "Carbolate," of Falmouth, to vessels of 5,776 tons, such as the Narragansett, of Greenock. He gives a list of 54 tank sailing vessels, with a net tonnage varying from 111 to 6,970. In his list of vessels fitted for using liquid fuel, he mentions 203, the gross tonnage varying from 75, as in the "Krungthep," of the East Asiatic Company, Limited, to 13,454, as in the "Tenyo Maru," of the Toyo Kisen Kabushiki Kaisha. The "Texan," of the American-Hawaiian S. S. Company, has a tonnage of 8,615, gross.

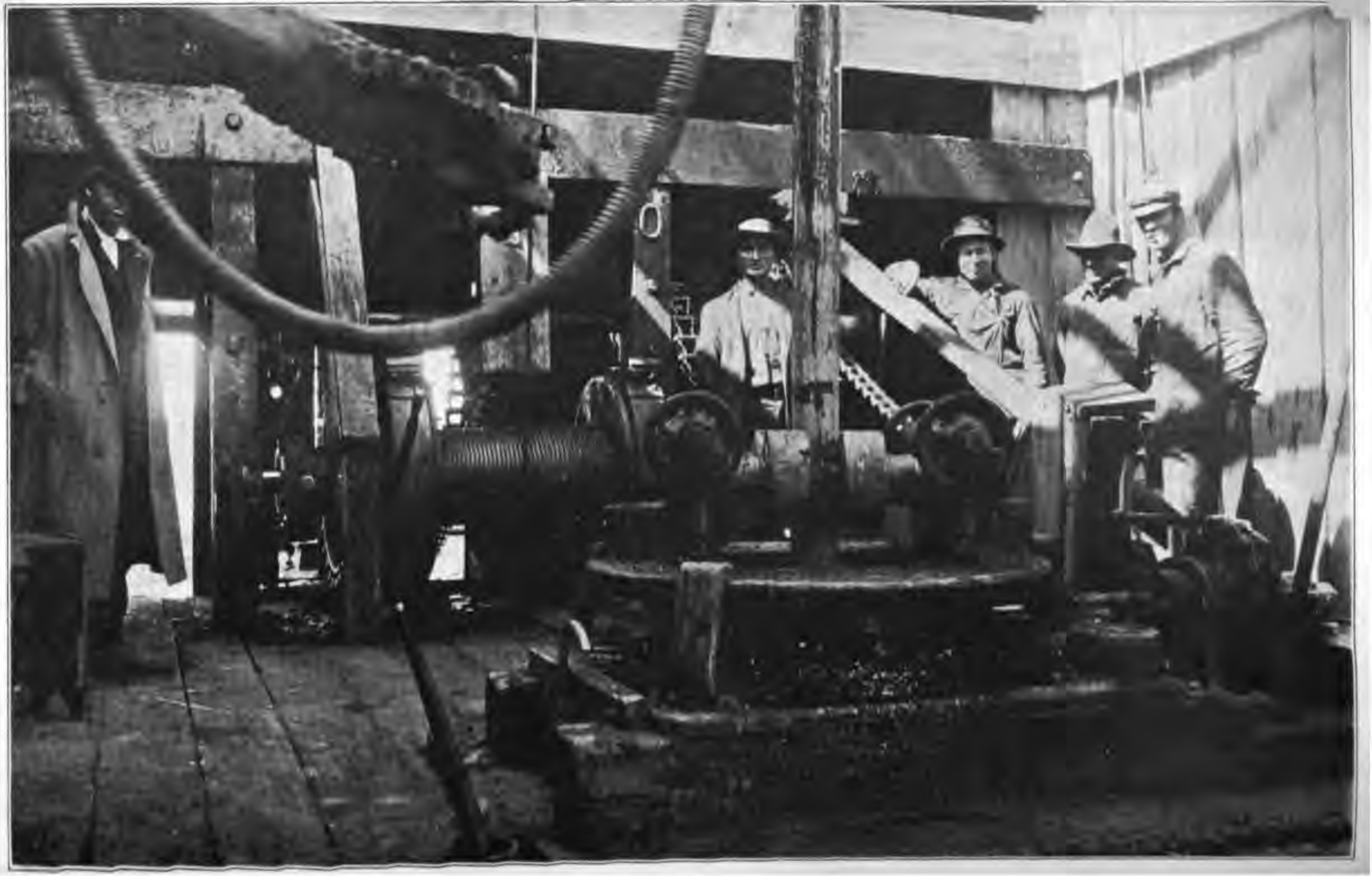
With respect to petroleum as fuel, the following is taken from Boverton Redwood's "Treatise on Petroleum," 3d edition, 1913, pages 381 to 383:

"For many years Russia was the only country producing and consuming liquid fuel on a scale of commercial magnitude, the crude petroleum from the prolific oil fields of Baku yielding a large proportion of a suitable product, but for some time past there has been in the United States a rapid growth in the general employment of liquid fuel, large supplies being obtained in California and elsewhere. The Kutei district of Borneo has also become an important factor in the industry, the petroleum found there yielding an excellent fuel oil and being apparently obtainable in very large quantities. Among other present and prospective sources of supply to which the now general recognition of the advantages of liquid fuel, especially for marine purposes, has caused attention to be directed, are those of Burma, Persia, Egypt, Trinidad, Mexico, Galicia and Roumania, and there can be no doubt that the efforts now being made to develop fresh sources of supply will result in a very considerable increase in the quantity at present available. It would, however, be misleading to suggest that there is any prospect of a general substitution of oil for coal as fuel in steam-raising and for other purposes. The author pointed out in giving evidence before the Royal Commission on Coal Supplies in 1903, that if the aggregate output of petroleum in the world were doubled, and the whole of the surplus thus created were used as fuel, this surplus would, taking into account the relative thermal efficiencies, only be equivalent to about 5 per cent of the world's output of coal.

It has also to be taken into account that with the development of most oil fields there is a progressive decrease in the proportion of fuel oil yielded by the crude petroleum, the oil obtained at greater depth usually containing a larger proportion of the more volatile hydrocarbons. Lastly, the exhaustion of the older oil fields, which is proceeding *pari passu* with the opening up of new fields, must not be lost sight of in forming an estimate of the extent to which the world's supplies may be augmented. In this connection, attention should be drawn to a report in which Dr. David T. Day, the expert of the United States Geological Survey, in charge of petroleum investigation, gave the data on which he arrived, some three years ago, at the somewhat startling conclusion that at the present rate of increase of the output of petroleum, the known oil fields of that country would, on the basis of the estimated minimum quantity of oil obtainable, be exhausted by the year 1935, whilst if the present output were only maintained the supply would on the same basis only last for ninety years. In these circumstances it is fortunate that through the success which has attended the introduction of the Diesel engine, to which reference will be made subsequently, attention is now being given to the substitution of the internal-combustion engine for the steam-engine, for with the Diesel type of engine, it is possible to obtain about three times as much power from a given quantity of oil as is usually yielded when the oil is used for steam-raising in conjunction with the best types of steam-engine, though, as is hereafter pointed out, modern improvements in the raising and use of steam may be held to necessitate a revision of this comparison.

In their final report, dated 7th January, 1905, the Commissioners express themselves on the subject of the substitution of oil for coal, in the following terms:

"There has been much disposition in recent years to speak of oil fuel as if it were a serious competitor of coal, and a real substitute for it. The facts before us do not bear out that view. Dr. Boverton Redwood in his evidence has given us a valuable account of the present and prospective sources of supply of petroleum and its allied products, and while he thought there was ample scope for energy and capital in searching for and opening up fresh



sources of supply, he expressed himself very strongly against the possibility of any largely extended use of petroleum as a substitute for coal. He pointed out that the world's production of coal in 1901 was 777 million tons, and that in the same year the world's production of petroleum was 22 million tons, or only 2.8 per cent of the weight of the coal.

"The conclusion we have arrived at as regards the use of oil fuel in this country is that which is expressed by Dr. Boverton Redwood in answer to Question 13,559, when he said: 'I think there will be certain selected applications of liquid fuel where the advantages of employing such a fuel are especially obvious; but for anything like general employment, I cannot see where we are to look for adequate supplies' "

Liquid fuel is largely applied in metallurgical operations and has replaced coal in many glass-works and other industrial establishments. It has also been found available for domestic use, but the principal application has hitherto been for steam-raising.

The following specifications for the purchase of fuel oil for the United States Government was issued by the Bureau of Mines in 1911:

"General Specifications.

"1. In determining the award of a contract, consideration will be given to the quality of the fuel offered by the bidders, as well as the price, and should it appear to be to the best interest of the Government to award a contract at a higher price than that named in the lowest bid or bids received, the contract will be so awarded.

"2. Fuel oil should be either a natural homogeneous oil or a homogeneous residue from a natural oil; if the latter, all constitents having a low flash-point should have been removed by distillation; it should not be composed of a light oil and a heavy residue mixed in such proportion as to give the density desired.

"3. It should not have been distilled at a temperature high enough to burn it, nor at a temperature so high that flecks of carbonaceous matter began to separate.

"4. It should not flash below 60 degrees C. (140 degrees Fahrenheit) in a closed Abel-Pensky or Pensky-Martens tester.

"5. Its specific gravity should range from 0.85 to 0.96 at 15 degrees C. (59 degrees Fahrenheit); the oil should be rejected if its specific gravity is above 0.97 at that temperature.

"6. It should be mobile, free from solid or semi-solid bodies, and should flow readily, at ordinary atmospheric temperatures, and under a head of one foot of oil, through a 4-inch pipe 10 feet in length.

"7. It should not congeal nor become too sluggish to flow at 0 degrees C. (32 degrees Fahrenheit).

"8. It should have a calorific value of not less than 18,000 British thermal units per pound; 18,360 B. t. u. to be the standard. A bonus is to be paid or a penalty deducted according to the method stated under Section 21, as the fuel oil delivered is above or below this standard.

"9. It should be rejected if it contains more than 2 per cent water.

"10. It should be rejected if it contains more than one per cent sulphur.

"11. It should not contain more than a trace of sand, clay, or dirt.

"12. Each bidder must submit an accurate statement regarding the fuel oil he proposes to furnish. This statement should show:

(a) The commercial name of the oil.

(b) The name or designation of the field from which the oil is obtained.

(c) Whether the oil is a crude oil, a refinery residue, or a distillate.

(d) The name and location of the refinery, if the oil has been refined at all.

"13. The fuel oil is to be delivered f. o. b. cars or vessel, according to the manner of shipment, at such places, at such times, and in such quantities as may be required, during the fiscal year ending.

"14. Should the contractor, for any reason, fail to comply with a written order to make delivery, the Government is to be at liberty to buy oil in the open market and charge against the contractor any excess of price, above the contract price, of the fuel oil so purchased."

The specifications adopted by the State Purchasing Agent, Austin, Texas, for fuel oil to be supplied to the various State institutions for which he secures supplies, are as follows:

Fuel Oil.

"To be natural, crude, distilled or reduced petroleum, free from sand or other solid matter that will impede or prevent handling freely through ordinary size pumps, pipes, or burners, and to be of such viscosity that will permit of its being handled freely at a temperature of 60 degrees Fahrenheit. It shall be commercially free of water, and wherever practicable, all free water must be drawn from the delivery tanks before discharging. The specific gravity, as determined by the Tagliabue Hydrometer, shall be between 25 degrees and 30 degrees Baumé. The buyer may refuse to accept any fuel oils showing a flash point of less than 200 degrees Fahrenheit when tested by the open cup Tagliabue method; namely, heating the oil at the rate of 2 degrees per minute, flame test to be applied every 2 degrees after the temperature of the oil is raised, beginning at 90 degrees Fahrenheit. The burning point of fuel oil shall not be below 212 degrees Fahrenheit. The British thermal units per pound of fuel oil shall not be less than 19,000."

The total production and value of the petroleum in Texas for the years 1889 to 1912, inclusive, are as follows, barrels of 42 gallons:

Year.	Production.	Value.
1889	48	$ 340
1890	54	227
1891	54	227
1892	45	225
1893	50	210
1894	60	420
1895	50	350
1896	1,450	4,000
1897	65,975	65,975
1898	546,070	382,249
1899	669,013	473,443
1900	836,039	871,996
1901	4,393,658	1,247,351
1902	18,083,658	3,998,097
1903	17,955,572	7,517,479
1904	22,241,413	8,156,220
1905	28,136,189	7,552,262
1906	12,567,897	6,565,578
1907	12,322,696	10,410,865
1908	11,206,464	6,700,708
1909	9,534,467	6,793,050
1910	8,899,266	6,605,755
1911	9,526,474	6,554,552
1912	11,735,057	8,852,713
Total	168,721,719	$82,754,292

The following Tables, XVIII to XXI, give the production and value of Texas petroleum from 1902 to 1912, inclusive, in barrels of 42 gallons, the statistics used being those of the United States Geological Survey:

TABLE XVIII.

Production of Petroleum in Northern Texas, 1902-1912. Barrels of 42 Gallons. Statistics of the United States Geological Survey.

Year.	Corsicana, Navarro County.	Henrietta, (Petrolia) Clay County.	Powell, Navarro County.	Marion County.	Electra, Wichita County.	Total, including other districts.
1902..........	571,050	....	46,812	....	....	617,871
1903..........	401,817	....	100,143	....	....	501,960
1904..........	374,318	65,455	129,329	....	....	569,252
1905..........	311,554	75,592	132,866	....	....	520,282
1906..........	332,622	111,072	673,221	....	....	1,117,905
1907..........	226,311	83,260	596,897	....	....	912,618
1908..........	211,117	85,963	421,659	....	....	723,264
1909..........	180,764	113,485	383,137	....	....	681,940
1910..........	137,331	126,531	450,188	251,717	....	969,403
1911..........	128,526	168,965	373,055	677,689	899,579	2,251,193
1912..........	233,282	197,421	251,240	362,870	4,227,104	5,275,529
Total.....	3,108,692	967,744	3,558,547	1,292,276	5,126,683	14,141,217

TABLE XIX.

Value of petroleum in Northern Texas, 1902-1912. Barrels of 42 gallons.

Year.	Corsicana.		Powell.		Henrietta (Petrolia).		Electra.		Marion County.		Total value of all districts.
	Value.		Value.		Value.		Value.		Value.		
	Total.	Per bbl., cents.	Total.	Per bbl., cents.	Total.	Per bbl., cents.	Total.	Per bbl., cents.	Total.	Per bbl., cents.	
1902	410,536	71.89	9,863	21.07							$ 420,399
1903	458,071	114.	57,291	57.16							515,314
1904	315,656	87.	55,611	43.	65,455	47.5					412,360
1905	258,590	83.	66,433	50.	35,906	47.5					361,604
1906	310,941	93.5	356,144	52.9	72,197	65.					740,542
1907	228,845	101.1	407,186	68.2	78,946	94.8					721,577
1908	153,489	72.7	274,536	65.1	46,947	54.6					479,072
1909	130,335	72.1	199,952	52.2	58,694	51.7					393,732
1910	87,623	63.8	242,440	53.8	69,086	54.6					505,396
1911	74,439	57.9	186,528	50.	92,046	54.5	492,175	54.7			1,213,960
1912	149,393	64.	193,439	76.9	134,681	68.2	3,340,828	79.	290,974	80.2	4,112,826
Total and average	2,577,918	80.09	2,049,423	53.66	653,958	48.94	3,833,003	66.85	290,974	80.2	$9,876,782

TABLE XX.

Production of petroleum in Coastal Texas, 1902-1912. Barrels of 42 gallons. Statistics of the United States Geological Survey.

Year.	Batson, Hardin County.	Saratoga, Hardin County.	Sour Lake, Hardin County.	Matagorda County.	Spindle Top, Jefferson County.	Dayton, Liberty County.	Humble, Harris County.	Other districts.	Total, including other districts.
1902	....	44	838	....	17,420,949	....	....	....	17,465,787
1903	4,518	8,848	159	....	8,600,905	....	....	a.30	17,453,612
1904	10,904,737	739,239	6,442,357	151,936	3,433,842	....	....	a.50	21,672,161
1905	3,774,841	3,125,028	3,362,153	46,471	1,652,780	60,294	15,594,310	a.30	27,615,907
1906	2,289,507	2,182,057	2,156,010	3,600	1,077,492	92,850	3,571,445	77,031	11,449,992
1907	2,164,453	2,130,928	2,353,940	1,573	1,699,943	108,038	2,929,640	21,563	11,410,078
1908	1,593,570	1,631,786	1,595,060	62,640	1,747,537	39,901	3,778,521	31,185	10,483,200
1909	1,206,214	1,183,559	1,703,798	29,103	1,388,107	17,647	3,237,060	87,039	8,852,527
1910	1,113,767	1,024,348	1,518,723	455,999	1,182,436	9,582	2,495,511	129,497	7,929,863
1911	1,023,493	925,777	1,364,880	561,828	965,939	4,344	2,426,220	2,800	7,275,281
1912	844,563	1,116,655	1,175,108	613,292	822,916	12,151	1,829,923	44,920	6,459,528
Total	24,919,663	14,062,377	21,672,029	1,925,442	39,992,846	314,807	35,865,630	394,145	148,047,936

a Bexar county. Note.—The production of Saratoga and Sour Lake for 1902 and 1903 is included in the grand total. The Spindle Top (Beaumont) field came into production in January, 1901. During that year the yield was 5,185,883 barrels, valued at $949,307, or 18.3 cents per barrel.

TABLE XXI.

Value of petroleum in Coastal Texas, 1902-1912. Barrels of 42 gallons. Statistics of the United States Geological Survey.

Year.	Batson.		Saratoga.		Sour Lake.		Matagorda County.		Spindle Top.		Dayton.		Humble.		Total, including other districts, dollars.
	Value.		Value.		Value.		•Value.		Value.		Value.		Value.		
	Total, dollars.	Per bbl., cents.	Total, dollars.	Per bbl., cents.	Total, dollars.	Per bbl., cents.	Total, dollars.	Per bbl., cents.	Total, dollars.	Per bbl., cents.	Total, dollars.	Per bbl., cents.	Total, dollars.	Per bbl., cents.	
1902	....	......	8,967	20.	14,413	32.15	....	......	3,563,285	20.45	......	......	....	......	3,586,665
1903	1,125	25.	c2,212,039	25.	c	c	....	......	2,212,039	25.	......	......	....	......	7,002,165
1904	3,707,671	34.	244,660	33.	2,401,911	37.3	51,625	34.	1,337,655	38.9	......	......	....	......	7,743,860
1905	1,025,025	27.2	872,285	28.1	1,117,261	33.2	16,677	36.	612,282	37.	18,255	30.3	3,528,768	22.6	7,190,658
1906	1,199,625	52.4	985,543	45.	1,155,475	53.6	a41,556	51.6	666,287	61.8	40,265	43.4	1,736,165	48.6	5,825,036
1907	1,913,875	88.4	1,742,913	81.8	1,944,343	82.6	a10,811	81.5	1,521,304	89.5	80,559	74.6	2,456,892	83.9	9,680,286
1908	885,965	55.6	989,167	60.5	982,709	61.6	b33,267	42.9	1,030,403	58.9	19,818	49.7	2,269,341	60.	6,221,636
1909	851,138	70.6	864,938	73.8	1,227,73[illegible]	72.1	21,918	75.3	1,041,791	75.1	11,471	65.0	2,314,082	71.5	6,399,318
1910	851,927	76.5	789,761	77.1	1,203,920	79.3	250,050	54.8	961,758	81.3	6,815	71.1	1,927,879	77.3	6,100,359
1911	704,788	68.8	739,247	79.8	995,807	72.9	305,588	54,3	724,978	75.	2,946	67.8	1,864,598	76.8	5,340,592
1912	625,812	74.1	827,847	74.1	874,897	74.5	406,032	66.2	654,778	79.6	8,473	69.7	1,313,229	71.8	4,739,887
Total	11,766,951	57.26	10,277,367	54.35	11,918,530	54.47	1,137,524	55.17	14,326,560	58.41	188,602	58.95	17,410,954	64.06	69,830,462

a–Includes Hoskins Mound. b–Includes Goose Creek. c–Values of Saratogs and Sour Lake combined, estimated at 25 cents a barrel. The Spindle Top (Beaumont) field came into production in January, 1901. During that year the yield was 5, 185,883 barrels, valued at $949,307, or 18.3 cents per bbl.

The high-water mark of production was reached in 1905, when the amount was 28,136,189 barrels, but the high-water mark of value was in 1907, when the total value was $10,410,865. The 12,322,696 barrels produced in 1907 were worth $2,858,603 more than the 28,136,189 barrels produced in 1905.

Prior to the year 1900 practically all of the petroleum produced in Texas came from the Corsicana field. Since 1898 that field has maintained its reputation for supplying high grade oil, the average price, per barrel, being 80.09 cents during the 11 years ending with 1912. The total production of the Corsicana field may be taken at 5,290,000 barrels, valued at $4,700.000. The Powell field, also in Navarro county, yields a heavier oil than the Corsicana field. It came into production in 1902 and has yielded 3,558,547 barrels, valued at $2,049,423, or 53.66 cents a barrel. The Henrietta field, Clay county, came into production in 1904, and has yielded 967,744 barrels, valued at $633,958, or 48.94 cents a barrel.

The Electra field, Wichita county, came into production in 1911 and has produced 5,126,683 barrels, valued at $3,833,003, or 66.85 cents a barrel. This is also a high-grade oil.

The other oil field classed as belonging to northern Texas is in Marion county, in northeast Texas. It is the Caddo Lake district in Texas, and may be the west extension of the Caddo fields in Louisiana. It came into production in 1910, and has yielded 1,292,276 barrels, valued at $290,974, or 80.2 cents a barrel.

The entire production of all of the northern Texas fields may be taken at 16,235,715 barrels, valued at $11,535,021.

In coastal Texas the first of the great fields to come into production was that at Spindle Top (Beaumont), Jefferson county. It began to produce in January, 1901, and since that time has yielded 45,178,729 barrels, valued at $15,285,867, or an average of 33.8 cents a barrel.

Saratoga and Sour Lake, Hardin county, came into production in 1902. The statistics for these two fields are combined for the years 1902 and 1903, but since 1904 Saratoga has yielded 14,062,377 barrels, valued at $8,056,356, or 57.3 cents a barrel. Since 1904, Sour Lake has yielded 21,672,029 barrels, valued at $11,904,117 or 55.3 cents per barrel.

The Batson field, Hardin county, came into production in 1903, but it was not until 1904 that the yield was considerable. Since 1903, it has produced 24,919,663 barrels, valued at $11,766,951 or 57.26 cents per barrel.

Matagorda county (Markham, etc.) came into production in 1904 and has yielded about 2,000,000 barrels, valued at $1,137,524, or 55.17 cents per barrel.

Dayton, Liberty county, came into production in 1905, and since that time has yielded 314,807 barrels, valued at $188,604, or 58.95 cents a barrel.

The Humble field, Harris county, came into production in 1905 and has yielded 35,865,630 barrels, valued at $17,410,954, or 64.06 cents per barrel. During its first year, this field produced 15,594,310 barrels, but fell to 3,571,445 barrels the following year, and in 1912 produced only 1,829,923 barrels.

CHAPTER XIV.

COMPARATIVE EFFICIENCY OF FUELS.

In the following Tables, XXII, XXIII, XXIV and XXV, which, for convenience of reference, are placed together, we have endeavored to calculate the fuel cost of evaporating 1,000 pounds of water by means of coal, lignite, fuel oil and natural gas. Before beginning a discussion of these tables, it may be well to explain, as briefly as possible, some of the terms used in stating an analysis of a fuel.

As ordinarily given, an analysis of coal and lignite contains six items, viz.: moisture, volatile combustible matter, fixed carbon, ash, sulphur and British thermal units per pound.

The moisture in such fuel is the usual atmospheric moisture and is removed at or near the boiling point of water, 212 degrees Fahrenheit. If the temperature be increased much beyond this point, incipient decomposition of the coal or lignite sets in and occasions a loss which is not chargeable to ordinary moisture alone. It includes certain volatile substances which may or may not contain appreciable heat units, according to circumstances. In drying coal and lignite, care must be taken that the temperature shall not exceed 215 to 220 degrees Fahrenheit. In some lignite a serious loss of volatile combustible matter is apt to occur above 220 degrees Fahrenheit and in exceptional cases at temperatures considerably below that of boiling water.

If we take the sample which has been deprived of its moisture and heat it in a platinum crucible set inside of another crucible, each being provided with a close fitting cover, we notice that vapors and smoke begin to arise, a flame appears and restricted combustion sets in. After a few minutes, the two crucibles being red-hot, these phenomena cease and there remains a solid residue in the inside crucible. The loss in weight that the fuel sustains is termed "volatile combustible matter." It may and often does contain gases that are not combustible, such as carbonic acid, etc.; but, irrespective of the content of such gases, it has been agreed among chemists to consider the loss as representing the volatile combustible matter in the fuel.

The solid residue in the crucible is the fixed carbon of the fuel, plus the mineral matter (ash). If the inner crucible be now exposed to the air and the carbon in the residue be burned away, we have only the ash remaining.

The volatile combustible matter and the fixed carbon are the heat producing constituents of the fuel, no account being taken of the sulphur, as this yields but little heat when burned.

The sulphur in coal and lignite exists, probably, in three conditions, as pyrite (sulphide of iron), as gypsum (sulphate of lime) or other analogous sulphates, and as more or less obscure organic compounds.

The expression "British thermal units per pound" is the method of stating the heat units in a pound of fuel, in the case of solid and liquid fuels, or in a cubic foot, as in gases. It means the quantity of heat required to raise the temperature of one pound of water one degree, the starting point being 39.1 degrees Fahrenheit. Some authorities prefer to take the starting point at 54 degrees Fahrenheit, others at 62 degrees Fahrenheit, but there is no practical difference in the results, inasmuch as the specific heat of water at all temperatures from the freezing point to the boiling point is virtually the same. If a fuel is said to have 12,000 British thermal units (abbreviated to B. t. u.) per pound, we understand that each pound of this fuel, when properly burned, will give enough heat to raise the temperature of 12,000 pounds of water from 39.1 degrees to 40.1 degrees Fahrenheit, from 54 degrees to 55 degrees Fahrenheit, or from 62 degrees to 63 degrees Fahrenheit.

The B. t. u., therefore, gives a convenient method of comparing one fuel with another, and it is in general use in England and the United States. In Continental Europe, the term "calorie" is used, and this means the quantity of heat required to raise the temperature of one kilogram (=2.22 pounds of water) one degree Centigrade; i. e., from 0 to 1 degree. To convert B. t. u. to calories multiply by 0.555; to convert calories to B. t. u., multiply by 1.8. The B. t. u. is equivalent to 778 foot-pounds of work.

To evaporate one pound of water from and at 212 degrees Fahrenheit requires 965.7 heat units, or 535.96 calories; and this is equivalent to the oxidation of 0.0664 pounds of carbon. One horsepower is equivalent to 2544.987 heat units per hour.

The heat units in various substances differ according to the chemical composition. When the purest form of carbon—crystallized diamond—is burned to carbonic acid, there are generated 20,041 B. t. u. per pound; ordinary soft coal gives from 12,000 to 14,000; lignite (natural condition) 7,000 to 7,500; natural gas from 600 to 1,170 per cubic foot; fuel oil from 18,000 to 21,000 per pound.

The B. t. u. per pound of the best fuel oils are about the same as the B. t. u. of the diamond, although the chemical composition is vastly different.

The quantity of air, in cubic feet, required for the perfect combustion of a pound of fuel, varies from 73, in the case of dry wood to 162 for coke. Ordinary soft coal requires 143 and lignite 112. Crude petroleum (fuel oil) requires 173 and natural gas 227. These figures are subject to variations depending on the composition of the fuels, methods of burning, etc.

TABLE XXII.

Fuel cost of evaporating 1000 pounds of water with coal.

$$\text{Cost of evaporating 1000 pounds of water} = \frac{\text{Price of coal per ton}}{2 \times \text{evaporation.}}$$

Cost of coal per ton of 2,000 pounds.	$3.00	$3.50	$4.00	$4.50	$5.00	$5.50	$6.00	$6.50	$7.00	$7.50	$8.00
Pounds of water evaporated per pound of coal. / Cost of coal consumed in evaporating 1,000 pounds of water.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
5.0	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00	75.00	80.00
5.5	27.27	31.82	36.36	40.91	45.45	50.00	54.54	59.09	63.63	68.19	72.73
6.0	25.00	29.16	33.33	37.50	41.67	45.83	50.00	54.17	58.33	62.50	66.67
6.5	23.07	26.92	30.77	34.61	38.46	42.31	46.16	50.00	53.84	57.69	61.54
7.0	21.43	25.00	28.57	32.14	35.71	39.29	42.86	46.43	50.00	53.57	57.14
7.5	20.00	23.33	26.67	30.00	33.33	36.67	40.00	43.33	46.67	50.00	53.33
8.0	18.75	21.87	25.00	28.12	31.25	34.38	37.50	40.62	43.75	46.87	50.00
8.5	17.64	20.59	23.53	27.06	29.41	32.35	35.29	38.23	41.18	44.12	47.06
9.0	16.67	19.44	22.22	25.00	27.77	30.56	33.33	36.11	38.88	41.67	44.44
9.5	15.78	18.42	21.05	23.68	26.32	28.95	31.58	34.21	36.84	39.47	42.11
10.0	15.00	17.50	20.00	22.50	25.00	27.50	30.00	32.50	35.00	37.50	40.00
10.5	14.28	16.67	19.04	21.43	23.81	26.19	28.57	30.95	33.33	35.71	38.10
11.0	13.60	15.91	18.18	20.45	22.72	25.00	27.27	29.54	31.81	34.09	36.36

TABLE XXIII.

Fuel cost of evaporating 1000 pounds of water with lignite.

$$\text{Cost of evaporating 1000 pounds of water} = \frac{\text{Price of lignite per ton}}{2 \times \text{evaporation.}}$$

Cost of lignite per ton of 2,000 pounds.		$1.00	$1.10	$1.20	$1.30	$1.40	$1.50	$1.60	$1.70	$1.80	$1.90	$2.00
Pounds of water evaporated per pound of lignite.	Cost of lignite consumed in evaporating 1,000 pounds of water.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
3.0		16.67	18.33	20.00	21.67	23.33	25.00	26.67	28.33	30.00	31.67	33.33
3.5		14.28	15.71	17.14	18.57	20.00	21.43	22.86	24.28	25.71	27.14	28.57
4.0		12.50	13.75	15.00	16.25	17.50	18.75	20.00	21.25	22.50	23.75	25.00
4.5		11.11	12.22	13.33	14.44	15.55	16.67	17.78	18.89	20.00	21.11	22.22
5.0		10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
5.5		9.09	10.00	10.91	11.82	12.73	13.64	14.56	15.45	16.37	17.27	18.18
6.0		8.33	9.17	10.00	10.83	11.67	12.50	13.33	14.16	15.00	15.83	16.66
6.5		7.69	8.46	9.23	10.00	10.77	11.54	12.31	13.07	13.84	14.61	15.39
7.0		7.04	7.85	8.57	9.28	10.00	10.71	11.43	12.14	12.85	13.57	14.28
7.5		6.67	7.33	8.00	8.67	9.33	10.00	10.67	11.34	12.00	12.67	13.33
8.0		6.25	6.87	7.50	8.12	8.75	9.37	10.00	10.62	11.25	11.87	12.50

TABLE XXIV.

Fuel cost of evaporating 1000 pounds of water with fuel oil.

Assuming that 3.75 barrels of oil (=1200 pounds) are equivalent to one ton (2000 pounds) of coal we have:

Cost of evaporating 1000 pounds of water $=\frac{\text{Price of oil per 3.75 bbls.}}{2 \times \text{evaporation.}}$ The price per bbl. starts at 80 cents and increases by 5 cents up to $1.30.

Cost of oil per 3.75 barrels. (Equal one ton of coal.)	$3.0	$3.05	$3.10	$3.15	$3.20	$3.25	$3.30	$3.35	$3.40	$3.45	$3.50
Pounds of water evaporated per pound of oil. — Cost of oil consumed in evaporating 1,000 pounds of water.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
10.0	15.00	15.25	15.50	15.75	16.00	16.25	16.50	16.75	17.00	17.25	17.50
10.5	14.28	14.52	14.76	15.00	15.24	15.48	15.72	15.96	16.20	16.44	16.68
11.0	13.64	13.87	14.10	14.33	14.56	14.79	15.02	15.25	15.48	15.71	15.94
11.5	13.04	13.26	13.48	13.72	13.96	14.20	14.44	14.68	14.92	15.16	15.40
12.0	12.50	12.71	12.92	13.13	13.34	13.55	13.76	13.97	14.18	14.39	14.60
12.5	12.00	12.20	12.40	12.60	12.80	13.00	13.20	13.40	13.60	13.80	14.00
13.0	11.54	11.73	11.92	12.11	12.30	12.49	12.68	12.87	13.06	13.25	13.44
13.5	11.11	11.29	11.48	11.66	11.84	12.02	12.20	12.38	12.56	12.74	12.92
14.0	10.71	10.89	11.07	11.25	11.43	11.61	11.79	11.97	12.15	12.33	12.51
14.5	10.34	10.52	10.70	10.88	11.06	11.24	11.42	11.60	11.78	11.96	12.14
15.0	10.00	10.16	10.33	10.50	10.67	10.84	11.01	11.18	11.35	11.52	11.69
15.5	9.68	9.84	10.00	10.16	10.32	10.48	10.64	10.80	10.96	11.12	11.28
16.0	9.37	9.53	9.67	9.85	10.00	10.15	10.30	10.45	10.60	10.75	10.90

TABLE XXV.

Fuel cost of evaporating 1000 pounds of water with natural gas.

Assumption: 30,000 cubic feet of 800 B. t. u. gas=2000 pounds coal of 12,000 B. t. u.

Cost of natural gas per 1,000 cubic feet.			Cents. 10	Cents. 12.5	Cents. 15	Cents. 17.5	Cents. 20	Cents. 22.5	Cents. 25	Cents. 27.5	Cents. 30	Cents. 32.5	Cents. 35
Pounds of water evaporated per 1,000 cubic feet of gas.	500	Cost of gas consumed in evaporating 1000 pds. of water.	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00
	550		18.18	22.73	27.27	31.82	36.36	40.90	45.44	49.98	54.52	59.06	63.60
	600		16.66	20.83	25.00	29.17	33.34	37.51	41.68	45.85	50.02	54.19	58.36
	650		15.38	19.23	23.08	26.93	40.78	44.63	48.48	52.33	56.18	60.03	63.88
	700		14.29	17.86	21.43	25.00	28.57	32.14	35.71	39.28	42.85	46.42	49.99
	750		13.33	16.67	20.00	23.33	26.67	30.00	33.33	36.67	40.00	43.33	46.67
	800		12.50	15.62	18.75	21.87	35.00	38.12	41.24	44.36	47.48	50.60	53.72
	850		11.76	14.70	17.65	20.59	23.53	26.47	29.41	32.35	35.29	38.23	41.17
	900		11.11	13.90	16.67	19.44	22.21	24.98	27.75	30.52	33.29	36.06	38.83

Explanation of Tables XXII, XXIII, XXIV, and XXV.

The tables relating to coal, lignite and fuel oil are based on the assumption that the cost of evaporating 1,000 pounds of water from and at 212 degrees Fahrenheit is equal to the price of the fuel, per ton or per barrel, divided by twice the evaporation. What has to be known, therefore, is the price of the fuel and the number of pounds of water that one pound of the fuel will evaporate. In the case of coal, Table XXII, we have assumed that the price of the coal varies from $3.00 to $8.00 per ton of 2,000 pounds and that the evaporative power, per pound of coal, varies from 5 to 11 pounds of water. It would be a singularly inefficient coal that would evaporate as little as 5 pounds of water per pound and it would be a coal of extraordinary quality, burned under very exceptional conditions, that would give a higher evaporation than 11 pounds.

If the coal costs $3.00 a ton, the fuel cost of evaporating 1,000 pounds of water, with an evaporative power of 5, would be 30 cents; it would be 25 cents with an evaporative power of 6; and 21.43 cents with an evaporate power of 7. If the coal should cost $4.00 a ton these figures become 45 cents, 37.50 cents, and 32.14 cents, respectively. If the coal should cost $5.00 a ton, these figures would be 50 cents, 41.67 cents, and 35.71 cents, respectively.

The higher the evaporative power, the more can one afford to pay for the coal. To evaporate 1,000 pounds of water with a coal costing $3.00 a ton, and an evaporation of 5, costs as much as the same service with coal at $4.50 a ton and an evaporation of 7.5, or as the same service with coal at $6.00 a ton and an evaporation of 10. There is a real economy in using the best coal and in burning this coal under conditions that will secure the highest evaporation. If the best coal cannot be secured, then a proper attention to the conservation and use of the heat units in the inferior coal will often counterbalance the difference in quality. This point is of especial importance in many places in Texas where there is a possibility of competition between coal and lignite, between coal and fuel oil, and between lignite and fuel oil.

In regard to lignite, Table XXIII, we have assured that the price will vary from $1.00 to $2.00 a ton and that the evaporative power will vary from 3 to 8 pounds per pound of lignite. Unless dry lignite should be used, it is not likely that we will have to consider as high an evaporative power as 8.

With lignite at $1.00 a ton and an evaporative power of 3 pounds, the fuel cost of evaporating 1,000 pounds of water will be 16.67 cents; with lignite at $1.50 a ton the cost will be 25 cents and with lignite at $2.00 a ton, the cost will be 33.33 cents.

If, however, we take lignite at $1.00 a ton, and an evaporation of 5, the fuel cost of evaporating 1,000 pounds of water will be 10 cents; with lignite at $1.50 a ton, the cost will be 15 cents; and at $2.00 a ton, 20 cents.

Let us now compare coal and lignite a little more in detail. We will assume that coal costs $4.00 a ton and that it will evaporate 6.5 pounds of water per pound. Under these conditions, the fuel cost of evaporating 1,000 pounds of water will be 30.77 cents. This fuel cost is very nearly equivalent to lignite at $2.00 a ton with an evaporation of 3 pounds of water per pound. An evaporation of 5 pounds of water per pound of lignite has been reached in actual practice and under this condition, if the lignite costs $2.00 a ton, the fuel cost of evaporating 1,000 pounds of water will be 20 cents.

In other words, if $4.00 coal, evaporating 6.5 pounds of water, has a fuel cost, per 1,000 gallons of water evaporated, of 30.77 cents, the same service can be performed for 20 cents with lignite at $2.00 a ton.

It would appear to be possible to secure from lignite an evaporation of 5.5. If this can be done, it would have an advantage of 12 cents per 1,000 pounds of water over $4.00 coal with an evaporation of 6.5.

In regard to fuel oil, we have assumed prices per barrel of 42 gallons (=320 pounds) varying from 80 cents to $1.30, and an evaporation from 10 to 16 pounds. The table is constructed on the basis of 3.75 barrels of oil being equivalent to one ton of coal. Results of extensive investigations have shown that the amount of oil equivalent to one ton of coal varies from 3½ to 4 barrels, so that we have taken 3.75 barrels as an average equivalent.

If we take fuel oil at 80 cents a barrel, allow that 3.75 barrels are equivalent to a ton of coal and that the evaporation is 10, we have 15 cents as the fuel cost of evaporating 1,000 pounds of water.

This cost is the same as the cost of evaporating 1,000 pounds of water with $3.00 coal having an evaporation of 10 and is the same as the cost of evaporating 1,000 pounds of water with lignite at $1.20 and an evaporation of 4.

These costs do not include the cost of handling the coal or lignite into the plant, the cost of firing or that of removal of ashes and refuse. Such matters involve local conditions that we do not here discuss, as each case has to be judged on its own merits.

At points of considerable consumption within the State, fuel oil is now selling at $1.20 a barrel. If we allow that 3.75 barrels are equivalent to a ton of coal, the cost of evaporating 1,000 pounds of water with this oil (evaporation, 10) is 17 cents; with evaporation 10.5, it is 16.20 cents; with evaporation 11, it is 15.48 cents; with evaporation 12, it is 14.18 cents.

We bring the matter into a more convenient form to show the relative values obtainable from $100 expended on coal, lignite and fuel oil. We will allow that the coal costs $5.00 a ton and has an evaporation of 7; that the lignite costs $2.00 a ton and has an evaporation of 4; and that the oil costs $1.20 a barrel and has an evaporation of 12. Under these assumptions, how many pounds of water can be evaporated for $100, no account being taken of the costs attendant on the handling of the fuel or the refuse from the coal and lignite?

$100 will buy 83.33 barrels of oil, which, with a factor of 12, will evaporate 319,987 pounds of water.

$100 will buy 20 tons of coal, which, with a factor of 7, will evaporate 280,000 pounds of water.

$100 will buy 50 tons of lignite which, with a factor of 4, will evaporate 400,000 pounds of water.

If we extend this comparison to include natural gas (see Table XXV) at 10 cents, per 1,000 cubic feet, and a factor of 700 we find that $100 will buy 1,000,000 cubic feet, which will evaporate 700,000 pounds of water.

Natural gas is by far the cheapest and best fuel, but it is not within reach of the greater part of the State. Even if it were, we think that its use should be restricted to domestic purposes, in order that the supply might be conserved.

Next in value to natural gas as a fuel, comes fuel oil. This is within reach of nearly all parts of the State, but we are unable to see how the supply is to keep pace with the demand. During the last few years, we have seen the price double itself twice, and the tendency now is steadily upward. If we have not already reached the point where the advantages of this fuel are debatable, owing to the increase of price, we are certainly not far from it. With oil at $1.20 a barrel and an evaporative factor of 12, it is cheaper to use lignite at $2.00 a ton and a factor of 4. This disparity increases with the increase in price of the oil, and the decrease in price of the lignite. Furthermore, the advances that have been made in the burning of lignite under steam boilers will probably result in greater economies in this direction and this movement is far more pronounced than the movement towards additional supplies of fuel oil or lower prices. In lignite, whether burned as such or converted into gas, fuel oil faces its most serious rival, outside of consumption for railroad purposes.

With respect to natural gas some assumptions have to be made. If we allow that it requires 30,000 cubic feet of gas to equal one ton of soft coal, in heating power, we have to assume that this gas carries a certain number of B. t. u. per cubic foot, and that it is burned at a certain temperature and under a certain pressure.

It is impractical to construct a table that will take all of these things into consideration, so that what we shall have to offer is more of a general than a specific statement. We will allow that 30,000 cubic feet of gas of 800 B. t. u. per cubic foot are equivalent to to one ton of soft coal carrying 12,000 B. t. u. per pound and that the gas is burned at 70 degrees Fahrenheit and under 4 ounces pressure. Under these conditions Table No. XXI gives the cost of evaporating 1,000 pounds of water, if the gas varies in price from 10 to 35 cents per thousand cubic feet.

CHAPTER XV.

FREIGHT RATES ON COAL, LIGNITE AND PETROLEUM PRODUCTS.

RAILROAD COMMISSION OF TEXAS.

TWENTY-FIRST ANNUAL REPORT, 1912.

Commodity Tariff No. 4-B, Applying on Coal and Lignite—Carloads.
Effective March 10, 1899, with amendments in effect October 31, 1912.

Rates, in cents per ton of 2,000 pounds, for the transportation by railroads between points in Texas, of shipments of soft coal, slack coal, smithing coal, anthracite coal, coke, lignite and lignite briquettes, in carloads.

Section 1. Table of Rates—Explanation.

Columns headed No. 1 contain rates to apply on shipments transported over a single line of railroad or over two or more lines of railroad which are under the same management and control. Columns headed No. 2 contain joint rates to apply on shipments transported over two or more lines of railroad which are not under the same management and control.

TABLE NO. 1.

Rates on Soft Coal (Except Slack), Smithing Coal and Coke.

Distances, miles	Rates		Distances, miles	Rates	
	No. 1	No. 2		No. 1	No. 2
30 and less	55	70	260 and over 250	170	185
40 and over 30	60	75	270 and over 260	175	190
50 and over 40	65	80	280 and over 270	180	195
60 and over 50	70	85	290 and over 280	185	200
70 and over 60	75	90	300 and over 290	190	205
80 and over 70	80	95	310 and over 300	195	210
90 and over 80	85	100	320 and over 310	200	215
100 and over 90	90	105	330 and over 320	203	217
110 and over 100	95	110	340 and over 330	206	219
120 and over 110	100	115	350 and over 340	209	221
130 and over 120	105	120	360 and over 350	212	223
140 and over 130	110	125	370 and over 360	215	225
150 and over 140	115	130	380 and over 370	219	229
160 and over 150	120	135	390 and over 380	223	233
170 and over 160	125	140	400 and over 390	227	237
180 and over 170	130	145	410 and over 400	231	241
190 and over 180	135	150	420 and over 410	235	245
200 and over 190	140	155	430 and over 420	239	249
210 and over 200	145	160	440 and over 430	243	253
220 and over 210	150	165	450 and over 440	247	257
230 and over 220	155	170	460 and over 450	251	261
240 and over 230	160	175	470 and over 460	255	265
250 and over 240	165	180	480 and over 470	259	269

Distances, miles	Rates		Distances, miles	Rates	
	No. 1	No. 2		No. 1	No. 2
490 and over 480..........	263	273	650 and over 640..........	335	345
500 and over 490..........	267	277	660 and over 650..........	340	350
510 and over 500..........	271	281	670 and over 660..........	345	355
520 and over 510..........	275	285	680 and over 670..........	350	360
530 and over 520..........	279	289	690 and over 680..........	355	365
540 and over 530..........	282	292	700 and over 690..........	360	370
550 and over 540..........	285	295	710 and over 700..........	365	375
560 and over 550..........	290	300	720 and over 710..........	370	380
570 and over 560..........	295	305	730 and over 720..........	375	385
580 and over 570..........	300	310	740 and over 730..........	380	390
590 and over 580..........	305	315	750 and over 740..........	385	395
600 and over 590..........	310	320	760 and over 750..........	390	400
610 and over 600..........	315	325	770 and over 760..........	395	405
620 and over 610..........	320	330	780 and over 770..........	400	410
630 and over 620..........	325	335	790 and over 780..........	405	415
640 and over 630..........	330	340	Over 790.................	410	420

Note.—Rates on anthracite coal shall be ten (10) per cent higher than the rates in Table No. 1 above. (Circular No. 1939, effective December 5, 1903.)

TABLE NO. 2.

Rates on Slack Coal.

Distances, miles	Rates		Distances, miles	Rates	
	No. 1	No. 2		No. 1	No. 2
30 and less.............	40	55	390 and over 380..........	213	223
40 and over 30..........	45	60	400 and over 390..........	217	227
50 and over 40..........	50	65	410 and over 400..........	221	231
60 and over 50..........	55	70	420 and over 410..........	225	235
70 and over 60..........	60	75	430 and over 420..........	229	239
80 and over 70..........	65	80	440 and over 430..........	233	243
90 and over 80..........	70	85	450 and over 440..........	237	247
100 and over 90..........	75	90	460 and over 450..........	241	251
110 and over 100..........	80	95	470 and over 460..........	245	255
120 and over 110..........	85	100	480 and over 470..........	249	259
130 and over 120..........	90	105	490 and over 480..........	253	263
140 and over 130..........	95	110	500 and over 490..........	257	267
150 and over 140..........	100	115	510 and over 500..........	261	271
160 and over 150..........	105	120	520 and over 510..........	265	275
170 and over 160..........	110	125	530 and over 520..........	269	279
180 and over 170..........	115	130	540 and over 530..........	272	282
190 and over 180..........	120	135	550 and over 540..........	275	285
200 and over 190..........	125	140	560 and over 550..........	280	290
210 and over 200..........	130	145	570 and over 560..........	285	295
220 and over 210..........	135	150	580 and over 570..........	290	300
230 and over 220..........	140	155	590 and over 580..........	295	305
240 and over 230..........	145	160	600 and over 590..........	300	310
250 and over 240..........	150	165	610 and over 600..........	305	315
260 and over 250..........	155	170	620 and over 610..........	310	320
270 and over 260..........	160	175	630 and over 620..........	315	325
280 and over 270..........	165	180	640 and over 630..........	320	330
290 and over 280..........	170	185	650 and over 640..........	325	335
300 and over 290..........	175	190	660 and over 650..........	330	340
310 and over 300..........	180	195	670 and over 660..........	335	345
320 and over 310..........	185	200	680 and over 670..........	340	350
330 and over 320..........	189	203	690 and over 680..........	345	355
340 and over 330..........	193	206	700 and over 690..........	350	360
350 and over 340..........	197	209	710 and over 700..........	355	365
360 and over 350..........	201	212	720 and over 710..........	360	370
370 and over 360..........	205	215	730 and over 720..........	365	375
380 and over 370..........	209	219	740 and over 730..........	370	380

Distances, miles	Rates		Distances, miles	Rates	
	No. 1	No. 2		No. 1	No. 2
750 and over 740	375	385	780 and over 770	390	400
760 and over 750	380	390	790 and over 780	395	405
770 and over 760	385	395	Over 790	400	410

Rates shown in the table above will apply on nut, pea and slack coal, straight or mixed carloads. Nut, pea and slack coal shall consist of any and all coal that will pass through a bar screen with bars 1¼ inches apart, or through a screen with round holes two inches in diameter.

TABLE No. 3.

Rates on Lignite and Lignite Briquettes.

Distances, miles	Rates		Distances, miles	Rates	
	No. 1	No. 2		No. 1	No. 2
30 and less	32	47	380 and over 370	148	158
40 and over 30	35	50	390 and over 380	151	161
50 and over 40	40	55	400 and over 390	154	164
60 and over 50	44	59	410 and over 400	157	167
70 and over 60	48	63	420 and over 410	161	171
80 and over 70	53	68	430 and over 420	164	174
90 and over 80	57	72	440 and over 430	167	177
100 and over 90	60	75	450 and over 440	170	180
110 and over 100	63	78	460 and over 450	173	183
120 and over 110	66	81	470 and over 460	176	186
130 and over 120	69	84	480 and over 470	180	190
140 and over 130	72	87	490 and over 480	183	193
150 and over 140	76	91	500 and over 490	186	196
160 and over 150	79	94	510 and over 500	189	199
170 and over 160	82	97	520 and over 510	192	202
180 and over 170	85	100	530 and over 520	195	205
190 and over 180	88	103	540 and over 530	198	208
200 and over 190	91	106	550 and over 540	202	212
210 and over 200	95	110	560 and over 550	205	215
220 and over 210	98	113	570 and over 560	208	218
230 and over 220	101	116	580 and over 570	211	221
240 and over 230	104	119	590 and over 580	214	224
250 and over 240	107	122	600 and over 590	217	227
260 and over 250	110	125	610 and over 600	220	230
270 and over 260	113	128	620 and over 610	221	231
280 and over 270	117	132	630 and over 620	222	232
290 and over 280	120	135	640 and over 630	223	233
300 and over 290	123	138	650 and over 640	224	234
310 and over 300	126	141	660 and over 650	225	235
320 and over 310	129	143	670 and over 660	226	236
330 and over 320	132	145	680 and over 670	227	237
340 and over 330	135	147	690 and over 680	228	238
350 and over 340	139	150	700 and over 690	229	239
360 and over 350	143	152	Over 700	230	240
370 and over 360	145	155			

Minimum Weight.—The minimum weight of each carload shall be twenty (20) tons; provided, that when the actual weight of a shipment contained in a car loaded to its full capacity shall be less than twenty tons, then the actual weight of such shipment shall be charged for at the rate per ton applicable under this tariff.

Section 2.—Exceptions.

1. Galveston, Harrisburg & San Antonio Railway: Rates on coal to San Antonio, from Hartz, 80 cents per ton, and from Eagle Pass, 90 cents per ton.

2. Rio Grande & Eagle Pass Railway and International & Great Northern Railroad: Rate on coal from Minera and Cannel to San Antonio, 90 cents per ton.

3. Rio Grande & Eagle Pass Railway: Rate on coal, carloads, from Minera, Cannel and San Jose to Sanchez and Laredo, sixty-five (65) cents per ton of 2,000 pounds (Circular No. 2764, effective January 1, 1908.)

4. Rio Grande & Eagle Pass Railway and International & Great Northern Railroad: Bone coal, in carloads, minimum weight 20 tons per car, from Cannel and Minera to San Antonio, 80 cents per ton of 2,000 pounds. (Circular No. 834, effective May 10, 1899.)

6. Texarkana & Fort Smith Railway: Coal, in carloads, from Beaumont to Port Arthur, 40 cents per ton of 2,000 pounds. (Circular No. 906, effective August 15, 1899.)

7. Houston East & West Texas Railway: Lignite, in carloads, from lignite mine at Garrison to brick yard at Garrison, $3.00 per car. (Circular No. 1107, effective April 12, 1900.)

8. Lignite, in carloads, from Lytle to San Antonio, 30 cents per ton of 2,000 pounds. (Circular No. 1109, effective May 2, 1900.)

9. Houston East & West Texas Railway: Lignite, in carloads, from Tandy to Timpson, $4.00 per car. (Circular No. 1126, effective May 18, 1900.)

10. Galveston, Harrisburg & San Antonio Railway: Rate on coal and screenings, in carloads, from Rio Bravo mines to San Antonio, 80 cents per ton. (Circular No. 1269, effective February 9, 1901.)

11. Galveston, Harrisburg & San Antonio Railway: Coal, including screenings, in carloads, minimum weight 20 tons per car, from Dolchburg (Rio Bravo) and Hartz mines to Eagle Pass,

twenty (20) cents per ton. (Circular No. 1996, effective January 22, 1904.)

13. Galveston, Harrisburg & San Antonio Railway: Rate on coal, in carloads, from Eagle Pass to El Paso, $2.25 per ton of 2,000 pounds. (Circular No. 1552, effective March 8, 1902.)

14. Galveston, Harrisburg & San Antonio Railway: Rate on coal, in carloads, from Eagle Pass to Seguin, $1.00 per ton of 2,000 pounds. (Circular No. 1651, effective August 16, 1902.)

15. Texas Central Railroad: Rate on coal, in carloads, from Coal Mine, M. P. 158, to Cisco, 37½ cents per ton of 2,000 pounds. (Circular No. 1840, effective June 15, 1903.)

18. Rio Grande & Eagle Pass Railway: Bone coal or cullings, in carloads, from points on the Rio Grande & Eagle Pass Railway to points on the St. Louis, Brownsville & Mexico Railway, same rates as apply on lignite to the same points. (Circular No. 2251, effective May 1, 1905.)

22. Texas & Pacific Railway: Coal, all kinds, in carloads, from Fort Worth, to Powell's Spur, minimum weight 30 tons per car, twenty (20) cents per ton, when consigned to and for use of the city of Fort Worth. (Circular No. 2683, effective October 21, 1907.)

23. Texas Short Line Railway: Slack lignite, in carloads, minimum weight 60,000 pounds per car, from Hoyt to Grand Saline, twenty (20) cents per ton. (Circular No. 2715, effective December 18, 1907.)

24. Lignite, in carloads, from Alba to Grand Saline, via the M., K. & T. Ry. of Texas and Texas Short Line Railway or T. & P. Ry., thirty-two (32) cents per ton of 2,000 pounds. Rates from intermediate points not to be higher, and to intermediate points not to be affected. (Circular No. 2819, effective June 17, 1908.)

25. Between Houston or Galveston and Texas City: Coal, hard, carloads, 71½ cents per ton; coke, carloads, 65 cents per ton. (Circular No. 2852, effective August 1, 1908.)

26. International & Great Northern Railroad: Lignite, carloads, from Carr Coal Spur to Lytle, twenty-five (25) cents per ton. (Circular No. 2864, effective August 20, 1908.)

27. International & Great Northern Railroad: Lignite, carloads, for distances named between points on the I. & G. N. R. R.,

shall be subject to the following rates in cents per ton of 2,000 pounds:

10 miles and less	28
20 miles and over 10 miles	30
30 miles and over 20 miles	32

Exceptions Nos. 8 and 26 will remain undisturbed. (Circular No. 2883, effective October 1, 1908.)

29. Rio Grand & Eagle Pass Railway and International & Great Northern Railway: Coal, in carloads, from points on the Rio Grande & Eagle Pass Railway to Houston, rates at intermediate points not to be affected, $1.75 per ton. (Circular No. 3610, effective November 18, 1910.)

30. Paris & Mt. Plesaant Railroad: (a) Coal, all kinds, in carloads, from Paris Station to East Side Well (two miles east of Paris), five ($5.00) dollars per car. (Circular No. 3634, effective December 7, 1910.)

(b) Slack coal, carloads, from Paris to Ragland, thirty (30) cents per ton of 2,000 pounds, for municipal purposes. (Circular No. 3934, effective November 6, 1911.)

31. Rio Grande & Eagle Pass Railway: Small sized coal—crushed bone, bone, nut and duff, from Minera, Cannel, San Jose and Duff Washer to Laredo, fifty-five (55) cents per ton. Effective January 1, 1912, and expiring December 31, 1912. Exception No. 3 will continue to apply on coal, all kinds, except as above described. (Circular No. 3975.)

32. Texas Mexican Railway: Bone coal, nut coal, washed duff and other by-products, from points on the Rio Grande & Eagle Pass Railway to points on the Texas Mexican Railway, lignite tariff rates. (Circular No. 4058, effective April 1, 1912. Expires April 1, 1913.)

34. Gulf & Interstate Railway of Texas: On coal, coke and lignite, carloads, from Port Bolivar to points in Texas. Galveston rates. (Circular No. 3997, effective January 1, 1912.)

35. Galveston, Harrisburg & San Antonio Railway: Coal, carloads, from Lamar Spur to Eagle Pass, twenty-five (25) cents per ton of 2,000 pounds. (Circular No. 4104, effective July 15, 1912. Expires December 31, 1913.)

In addition, authority was given to the Galveston, Houston &

Henderson Railroad Company, April 16, 1898, to charge 7½ cents per hundred pounds for the transportation of less than carloads of coal, in lots of 2,000 pounds or more, from Houston and Galveston, to all points on this line.

COMMODITY TARIFF NO. 27-C.

Crude and Fuel Petroleum, also Asphaltum, Carloads.

Section 1.—Table of Rates.

Explanation.—Columns headed No. 1 contain rates to apply on shipments transported over a single line of railroad or over two or more lines of railroad which are under the same management and control; columns headed No. 2 contain rates to apply on shipments transported over two or more lines of railroad which are not under the same management and control.

Distances, miles	Rates		Distances, miles	Rates	
	No. 1	No. 2		No. 1	No. 2
6 and less	2½	4	100 and over 80	7	8½
10 and over 6	3	4½	125 and over 100	7½	9
15 and over 10	3½	5	150 and over 125	8	9½
20 and over 15	4	5½	175 and over 150	8½	9¾
30 and over 20	4½	6	200 and over 175	9	10
40 and over 30	5	6½	225 and over 200	9½	10
50 and over 40	5½	7	250 and over 225	10	10¾
60 and over 50	6	7½	Over 250	10½	10¾
80 and over 60	6½	8			

Section 2.—Exceptions.

1. *Differential Rates.*—Rates on shipments transported more than 250 miles from or to points in differential territory (as defined in General Tariff of Class Rates No. 3) shall be made by adding to the maximum common point rate of 10½ cents per 100 pounds the following differential rates, in cents per 100 pounds, to apply by continuous mileage:

Distances, miles	Rates	Distances, miles	Rates
50 and less	1	250 and over 200	5
100 and over 50	2	300 and over 250	5½
150 and over 100	3	Over 300	6
200 and over 150	4		

Crude oil in carload lots from Humble to Houston, 2½ cents per 100 pounds, minimum $15 per car. This rate is to be used only on shipments moving locally to Houston, and is not to be used as a factor in making through rates.

Solar oil, gas oil, steamer oil, in cans, boxed, in barrels or in tank cars, between points in Texas, will be subject to the rates named in this tariff for crude and fuel petroleum, plus 2½ cents per 100 pounds. Estimated weight of 7.4 pounds per gallon will also apply.

Section 3.—Minimum Carloads.

1. The minimum weight of shipments transported over lines of standard gauge shall be 38,000 pounds per car; provided, that when the actual weight of the petroleum contained in a car loaded to its full capacity shall be less than 38,000 pounds, then the actual weight of such shipment shall be charged for at the rates prescribed in this tariff.

2. The minimum weight of shipments transported over lines of narrow gauge shall be 20,000 pounds per car; provided, that shipments originating at points on lines of standard gauge and destined to points on or reached by lines of narrow gauge shall be charged for at the weight determined by the cars in which they were transported over lines of standard gauge.

3. The weight of 7.4 pounds per gallon shall be used in determining the carload weights above provided for.

Section 4.—Rates on Asphaltum.

Asphaltum, in carloads, minimum weight 24,000 pounds per car, transported by railroads between points in common point territory, fifteen (15) cents per 100 pounds, except where Class D is less.

Rates to or from points in differential territory shall be made by adding to the rate above authorized the current Class D differential.

Exceptions.

1. From Port Arthur and Port Neches to Galveston and Texas City (rates at intermediate points not to be affected), 12 cents.

2. From Galveston, Port Arthur and Port Neches to Laredo (rates to intermediate points not to be higher), 18 cents.

3. From Galveston, Port Arthur and Port Neches to Eagle Pass (rates to intermediate points not to be higher), 19 cents.

4. From Galveston, Port Arthur and Port Neches to El Paso (rates to intermediate points not to be higher), 22 cents. (Circular No. 2062, effective June 8, 1904.)

5. From Beaumont to Galveston, minimum weight 30,000 pounds per car (rates to, from or between intermediate points not to be affected), five (5) cents. (Circular No. 2070, effective June 28, 1904.)

Section 5.—Rates on Creosote Oil or Other Wood Preservative.

Creosote oil or other wood preservative, in carloads, transported by railroads between points in Texas, will be subject to the rates prescribed in this tariff for crude and fuel petroleum, plus 2½ cents per 100 pounds. Estimated weight per gallon 8.2 pounds, and minimum carload weight 38,000 pounds.

Existing rates, when lower than the rates herein prescribed, will remain in force. (Circular No. 2685, effective November 5, 1907.)

Exceptions.

1. Creosote oil, in barrels, carloads, from Sabine to Beaumont, five (5) cents per 100 pounds. (T. & N. O. Authority No. 97, effective June 5, 1903.)

2. Creosote oil, in carloads, minimum weight to be marked capacity of car used, at estimated weight per gallon of 8.2 pounds, from Galveston to Beaumont, six (6) cents per 100 pounds. (Circular No. 3236, effective October 26, 1909.)

CHAPTER XVI.

BIBLIOGRAPHY OF COAL, LIGNITE, NATURAL AND PRODUCER GAS AND PETROLEUM IN TEXAS.

BY WM. B. PHILLIPS.

The first mining company incorporated by the Republic of Texas seems to have been the Trinity Coal & Mining Company. The act creating this company was passed by the Fourth Congress of the Republic and was signed by David S. Kaufman, Speaker of the House, and David G. Burnet, President of the Senate. It was approved by President Mirabeau B. Lamar, January 25, 1840. The persons named as the incorporators were: Frederick B. Page, Elisha A. Rhodes, R. D. Johnson, Levi Jones, and William Henry Davidson. The Company was authorized to open and work mines of coal, lead, iron, and other minerals, and to quarry stone on or near the Trinity river. The capital stock was to be in 2500 shares of the value of $100 each, but permission was given to increase the capital stock of $500,000, if it should become necessary to do so. A curious provision of the act was that the company were required "from time to time to communicate to the President of the Republic or to the Congress their progess in mining, and such other information in geology, mineralogy, or the arts, as might be interesting in science or useful in any of the branches of domestic industry." It is interesting to note in this connection that the coal (lignite) seams within reach of the Trinity river were to be opened and worked, and this is one of the present purposes of the appropriation made by the United States Government for the improvement of the Trinity river. It would appear that as far back as 1840 there were persons who had in view the advantages to be offered by this river for the transportation of coal, etc. But four years previous to this time, and about the year 1836, the "literature" of the Texas & New Ireland Land Company contains references to the coal along the Rio Grande, below Laredo, and Lieut. B. P. Tilden, in "Notes on the Upper Rio Grande," Philadelphia, 1847, also speaks of the coal near Laredo.

William Kennedy, in his "Texas: the Rise, Progress and Prospects of the Republic of Texas," 1841, speaks of the coal as it was reported to him from various parts of the republic, and in Volume

I, page 118, he quotes from Almonte, who wrote about the year 1834, that bituminous coal was found on the river San Bernard, about 15 miles from San Felipe, by the road which leads from that town to Gonzales. He quotes Almonte as saying that precisely in the middle of the stream where he bathed at half past six in the afternoon of the month of August, 1834, he found the water so warm that he could not bear it for a minute.

It is not our intention in this bibliography to quote every single reference that has appeared in books and articles concerning Texas, for this would be an endless task, and we confine ourselves to references from which the student may derive useful information concerning coal, lignite, natural gas, producer gas and petroleum in this State. Before beginning this bibliography, however, we will quote, entire, a very interesting statement made concerning Texas, by R. C. Taylor in his "Statistics of Coal," Philadelphia, 1848. He gives as his authorities: the Houston Telegraph; the New Orleans Picayune; Notes sur le Texas, documens sur le Commerce extèrieur, Juillet, 1842; Kennedy's Texas; Report in 1834 to the "Rio Grande Land Company"; McCulloch, art. Texas; Iken's Texas, and "Notes on the Upper Rio Grande," by Lieut. B. P. Tilden, Philadelphia, 1847.

He says:

"*Pitch Lake.*—An announcement has been made of the existence, in Texas, within 100 miles from Houston, of a small lake that closely resembles the Pitch Lake of Trinidad. It is filled with bitumen or asphaltum, and is about a quarter of a mile in circumference. During the cool winter months its surface is hard, and is capable of sustaining a person. From November to March it is generally covered with water, which is acid to the taste; from which cause it has been commonly called the "Sour Pond." In the summer months a spring occurs, near the center of the lake, from which an oily liquid (probably petroleum) continually boils up, from the bottom. This liquid gradually hardens, on exposure to the air, and forms a black pitchy substance, similar to that which forms the sides of the lake. It is said to resemble, precisely, the bitumen of Trinidad; and the Texans conceive that, at some future day, it will be valuable for the production of gas for their cities. It burns with a very clear bright light, but gives out a pungent odor.

"Coal is now well known to exist abundantly in Texas, although the country has not been geologically examined. There is no doubt but coal prevails at intervals entirely across the country, in a northeast and southwest direction. Its general position is about two hundred miles from the coast.

"On the Trinity river, two hundred miles above Galveston, the coal region there was investigated in 1846, and found to be more extensive than was anticipated. A company, under the title of the 'Trinity Coal and Mining Company,' was incorporated by an act of the Texan Congress in 1840. Both anthracite and semi-bituminous coal, somewhat like the cannel, in appearance, occurs here.

"Mineral coal, in great abundance, prevails not far from the Mustang Prairie. It is also found, accompanied with excellent iron ore, in the vicinity of Nacogdoches. According to report, this coal is abundant, rich, and of a fine appearance.

"Mr. Kennedy, who has taken pains to collect information relative to the resources of Texas, although not an original investigator, says, in a work published in 1841, that 'in addition to iron, the utilitarian sovereign of metals, Texas possesses coal—the grand auxiliary of the arts which tend to enrich and civilize the world.' Coal, both anthracite and bituminous, abounds from the Trinity river to the Rio Grande. The coal on the latter river, above Dolores, has been represented by the agents of the *Texas and New Ireland Land Company* (an association broken up by the revolution in 1836) as of excellent bituminous quality.

"Formations of secondary limestone, with others of carboniferous sandstones, shales, argillaceous iron ore, and bituminous coal beds, are said to occupy a large portion of the interior of Texas. Westward of these occurs the inferior and Silurian strata, trilobite limestones, and transition slates. Beyond all, basaltic and primary rocks of the Rocky Mountains arise; while northward is the great salt lake of the Brazos, and the vast red saliferous region traversed by the exploring expeditions of Captain Pike and Major Long, and since made more familiar to us by Mr. Gregg and other travelers.

"A bed of coal extends across the Brazos river towards the Little Brazos and the San Andres, down which stream it may without difficulty be transported at high water.

"Near the city of Austin, on the eastern border of the Colorado, is a peak, called Mount Bonnell, overlooking Austin, and having a fall of seven hundred feet perpendicular to the bed of the Colorado. This and other hills, although not scientifically examined, are known to contain beds of anthracite coal.

"On the Rio Grande, southwest of Bexar, is a great abundance of bituminous coal. The navigation of this river is reported to be free for eight months in the year.

"In many parts of the rolling prairie region, coal, of fair quality, and iron ore have been found; and it is supposed that beds of these valuable minerals extend over a great part of the country.

"We have received some recent information of the character of the country bordering upon the Rio Grande, as far up as the Presidio de Rio Grande, from the notes of Lieutenant B. P. Tilden.

"On approaching Laredo, within forty or fifty miles, by the course of the river, and extending north of that town, a coal formation is traversed during that distance. Beds of coal are frequently to be seen, as are deposits of nitre and sulphur, and also thick beds of good fire-clay, at the bases of the bluffs. These strata, and the accompanying sandstone rocks, are supposed to be a prolongation of similar strata at Guerrera, on the Rio Salado, to the southwest; as they agree in their range and dip. The writer, who apparently is not very familiar with geological phenomena, dose not furnish any further details."

Mr. Taylor's statement in regard to the existence of beds of anthracite coal in Mount Bonnell, near Austin, seems to have been due to the exercise of a lively imagination, as also his statement with respect to the beds of nitre and sulphur on the Rio Grande, below Laredo. So far as known, there is no anthracite coal anywhere in Texas, nor any beds of nitre.

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Development and Histology of the Integument of the Nine-Banded Armadillo
(*Tatusia Novemcincta*)

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DEVELOPMENT AND HISTOLOGY OF THE INTEGUMENT OF THE NINE-BANDED ARMADILLO

(TATUSIA NOVEMCINCTA*)

INTRODUCTION

The principal point of interest connected with the integument of the armadillo is in the relation of the structure of the integument to studies in heredity. Since the integument is marked off into distinct areas, the question naturally arises, are these areas transmissible? The study of the development of the integument is indispensable in solving that problem. In doing this work, certain points must necessarily be discussed, namely, how is the dermal armor formed, when is it formed, and how nearly is the development of the integument related to that of other forms?

All of the details in the development of the integument are not worked out in this paper; for example, no attempt has been made to trace out the skin glands, but as far as observed they follow Römer's (92a) description. The ossification, too, is as he describes it, but since the material had been prepared before his paper was seen, and since he only gives two figures to show the stages in ossification, this phase of the development has been worked out through the 10 cm. embryo. Besides, the detailed work has been confined to the banded region, because it is more highly differentiated and because the arrangement of its scutes makes the work more simple.

REVIEW OF LITERATURE

Some studies have been made on the integument of Dasypidæ, but most of the papers are of a theoretical character, based upon the work of others, or else the material used was too meager to justify the conclusions that have been drawn. Work has also been done on the integument of other Edentates. Weber ('92), working on Manis, states that the scales begin after the outer part

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is hardened, and that the horny plates, which begin by the raising of the skin, are formed in the epidermis.

Welcher ('64), working on the development and structure of the skin and hairs of Bradypus, found that there was, in the 26.5 cm. embryo, a tight-fitting, sac-like epitrichium which was pushed off by the underlying hairs. Such an epitrichium is absent from Dasypus.

Among the earlier workers on the integument of Dasypus are: Rudolphi ('18), who found that there were bony plates under the epidermis; von Rapp ('43), who tells us that there are bony plates on the upper side of the animal, that these plates have hairs between them, and that there are no plates on the under side of the animal; Meyer ('48), who worked on a piece of dried integument, said that there were bony plates embedded in the cutis, and that there were short hairs between the scales; Leydig ('59), who says that the scales come from the epidermis; and Kerbert ('77), who worked on two Dasypus embryos. He says that the girdles are formed by folds of the skin, that the hairs first arise in the bands, that the exoskeleton is of secondary formation into bands, and that the anlage of a hair is a papilla.

The most detailed work on the armadillo integument is that done by Römer ('92a). He, however, worked only on the later stages of its development. The specimens which he was able to obtain were, of Dasypus novemcinctus, nine embryos of 5, 6, 7, 11, and 12 cm. length; of D. Villosus, six embryos of 10, 11, and 12 cm. length; and an adult D. setosus. His earliest stage is a little later than that shown in figures 21, 22, and 23.

MATERIAL AND METHODS

The work presented in this paper was done on the nine-banded armadillo, Tatusia novemcincta. The females were shipped and the embryos removed at laboratory. The embryos used ranged from a very young stage in which the epidermis was undifferentiated and the limb buds barely visible, up to those that breathed when removed, and ranged in size from less than 6 mm. to 100 mm. in length.

The specimens were usually fixed in Zenker's fluid. Some sections were made from a specimen fixed in 95% alcohol. Two of the older specimens, of 6.7 cm. and 7.7 cm. length were fixed in Kleinenberg's picro-sulphuric mixture.

To show the stages in the development of the bony plates, six sizes of embryos were used, as follows: 5.5 cm., 6.7 cm., 8.5 cm., 8.9 cm., and 10 cm. lengths. These were cleared in a 1% solution of KOH, the method for which was described by Dr. R. L. Moody of the University of Kansas. Since the embryos were large, one of each size was skinned, and the skin cleared, and another of each size, with the eyes and intestines removed, was cleared. It was found that the skin cleared much more satisfactorily than the whole embryos, for the latter went to pieces before all of the muscles and other inner structures cleared up sufficiently. The skins were then removed from the whole specimens and the two sets of skins were hardened and preserved in glycerine.

The stain used for sections was Delafield's Haematoxylin with Orange G for counter stain. In the specimen cleared in KOH, the plate, when it is just beginning to be formed, is more easily differentiated if a stain is used. Safranin is satisfactory for this.

The embryos were measured in the greatest length from head to rump in a line parallel to the dorsal surface.

Most of the figures were drawn with the aid of the camera lucida, either on a Zeiss or on a Spencer microscope. A few were made with the aid of the Bausch and Lomb projecting apparatus.

This work was done under the direction of Dr. Patterson, to whom I am indebted for advice and assistance.

THE ADULT INTEGUMENT

In order that the terminology used in connection with the embryonic stages may be clear, a description of the adult integument must be given first. There are present in Tatusia novemcincta five shields described for armadillos, namely: the head, the pectoral, the banded region, the pelvic, and the tail shields. All of these regions are made up of what are termed scutes; and these, in turn, are composed of plates, horny scutes, and associated hair groups.

Since this work is concerned almost entirely with the banded region (Fig. 1), this account is of that region. Each band is made up, on the average, of about sixty-one bony plates, one of which is shown in figure 2. The bony plate is marked off into two distinct regions, an anterior flat portion which is covered by the band just anterior to it, or by the pectoral shield in the case of the plates of the first band, and a posterior portion, which overlaps the band just posterior, or the plates of the pelvic shield in the case of the ninth band. The anterior part of the plate is unmarked except by blood-vessels or nerves, but the posterior part has on its upper surface four rows of markings. The two outer rows represent the places where the roots of the inter-scute hairs are imbedded (Fig. 2, H. P.). It has not been determined as to what is the cause of the inner rows of markings. There are three possible causes, viz: nerves, blood-vessels, and hairs, but no trace has been found of hair development in this region, although the manner of ossification, which is like that in the region of the inter-scute hairs, as well as the form of the prints, would suggest that there are hairs developed in that region.

The number of hair prints, and consequently the number of hairs to the scute, is not always the same. The number of posterior hairs (Fig. 2, P. H. P.) varies from two to four, four being the number which is most often found. When this variation occurs in an individual the scutes with two and three hairs are usually toward the ends of the bands. Sometimes, however, an individual may be found that has, as typical, the three-haired type of scute. This fact has not been brought out in the study of the embryos, because the sections were made from the middle portions of the bands where the three-hair type is not frequent, and because the three-hair type of individual is rare.[1]

The number of inter-scute hairs may also vary in different scutes as well as on the two sides of the same scute. For example in an individual one plate may have four hair prints on one side and five on the other (Fig. 2), another three and four, and still another four and four.

The central part of each plate is covered by a wedge-shaped horny portion which extends between the hair marks and has, therefore, the broad part of the wedge to the posterior. This is termed the primary scute. In between these wedges, and over the seams of the plates, are narrow wedges with the broad part extending to the anterior and showing an indentation over the plate seam. This wedge is the secondary scute. The part where the bands join is only slightly horny so that the bands have free play.

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[1] Newman and Patterson, '11.

Corresponding to the hair markings described above for the plate there are hairs. Between the primary and secondary scutes are short, rather fine hairs (Fig. 1, I. H.) which may not be present in the older specimens, though the imprint may be seen in the horn. The posterior hairs (Fig. 1, P. H.) are heavier, more bristly, and longer than the inter-scute hairs. The variation in length in the two kinds of hairs is evidently due to wear.

THE EPIDERMIS

In the early stages in the development of the armadillo, there is the undifferentiated ectoderm (Fig. 3). In this stage the nuclei are round or oval. They occur in one layer over the dorsal part of the embryo, but on the sides they are sometimes four deep. Where there is but one layer, the nuclei are usually round, but if elongated the greatest length is parallel to the surface of the ectoderm. When the number of the nuclei increases, the elongation is perpendicular to the surface. When there is more than one layer, all may be round or some round and some elongated. There is a tendency for the inner layer to develop numerous nuclei, and for them to become elongated in a perpendicular direction before nuclei are added as an outer layer.

As is to be expected, there is little cytoplasm, especially in the region where the nuclei are numerous. There are cell walls which may be distinguished at some places better than at others; for example, the cells with perpendicular elongated nuclei have walls that may be easily made out. The same thing is true of the cells that are in a single layer.

After the nuclei which make up the inner layer have become rather numerous, some of them begin to crowd up to the surface. This feature is shown even in the earliest stages which are figured in this paper (Fig. 3, X). When the cells reach the surface both they and their nuclei flatten out and there will be found only an occasional surface cell (Fig. 4, E), but later, enough flatten out to form a continuous layer. Thus we have the two-layered epidermis, the outer layer or epitrichium, and the inner layer or stratum germinativum. The epitrichium consists of cells which are first spindle-shaped then flat, and which have nuclei that appear long and flat in section. The stratum germinativum has elliptical or rounded nuclei. The nuclei of the outer layer stain much more deeply than those of the inner layer (Fig. 5, E).

Further differentiation of the epidermis is brought about by the formation of a layer of cells between the epitrichium and the stratum germinativum and take up a position between the two layers that are already formed (Fig. 6, X). The intermediate layer later becomes best developed at certain points, namely, at the center of the scute primordium, although it is still represented in other regions by an occasional cell (Fig. 9), even as late as the 4.9 cm. embryo. The cells of the intermediate layer increase in number so that the epidermis of this region becomes several layers thick (Figs. 7, 9y, and 15).

The thickening of the epidermis to form the scute takes place first in the posterior part of the band, and it is greatest in the region of the posterior hairs (Fig. 15). The thickening decreases until the anterior part of the band is reached. Here we only find three layers in the 5.5 cm. embryo (Fig. 22) and two layers in the 4.9 cm. one (Fig. 7). More cells are continually added until there is an outer layer of flattened cells, a middle layer of polygonal cells, and a lower layer of columnar cells (Fig. 12). Gradually the cells of the outer layer, which is now several cells thick, become cornified and the nuclei and cytoplasm shrink. The nuclei disappear altogether, especially in the outer layers of the cells in the older stages, as is shown in figures 13, and 14, H, which are from a section of a 7.7 cm. embryo. The cells just beneath the corneous layer are elongated in a direction parallel to the surface and contain granules, from which they get the name, stratum granulosum (Fig. 14, S. G.). The nuclei of these cells, of which there may be several layers, are elongated in the direction with the long axis of the cells. The cells between the stratum and the lowest layer which is of columnar cells, may have elongated nuclei in the cells toward the surface and round nuclei in the inner cells (Fig. 14, I. C.).

THE HAIR

The anlage of the hair is found in an early stage in the development of the integument. The hair is formed from the epidermis.

Its beginning is characterized by an increase in the number of nuclei in the stratum germinativum. This condition is shown in Fig. 7, which is drawn from a 4.9 cm. embryo. As this thickened area grows down into the corium, it is at first in the form of a bowl, but as further inward growth takes place, a bulb is formed. It is at this last stage that we find the anlage of the papilla, which is a collection of nuclei in the corium at the inner end of the bulb (Fig. 11, P.).

The first hair formed is the one on the posterior part of the overlapping end of the scute. This hair is developed anterior to the edge of the scute fold, as is shown in Fig. 7. The hair grows further to the anterior, and the integument folds over until in the 7.7 cm. embryo the root of the hair is far to the anterior, although the hair now comes out from the posterior end of the scute (Fig. 13). The next hairs form in order in the scute from posterior to anterior so that we get, in a longitudinal section of a band, as many stages in the development of the hairs as there are hair sections. This is shown in Figs. 22 and 23. Two figures must be used to show this condition, because the hairs are not all in a line perpendicular to the anterior and posterior margins of the band, and a section through the hair region made perpendicular to the margins will not show all of the hairs (Fig. 2). Fig. 23 shows a section of the posterior hair of the region represented in Fig. 22. Numbering the hairs as they occur in order in the section, obviously 3 is a further advanced stage than 1, and 5 is the most highly differentiated stage of all. This same point, namely, that the posterior hairs are far in advance of the other hairs is brought out in the KOH cleared specimens, as well as the fact that the two middle posterior hairs of a scute are formed before the two outer posterior hairs are. The later stages in the development of the hairs follow out the process as it is in other mammals, a fact which Figs. 13 and 14 will suggest; and so the process will not be further described.

THE CORIUM

The epidermis, in the early stages of the development of the integument, is not closely connected with the mesenchyme (Fig. 3), but the connection is more intimate later, as is shown in Fig. 4. By the time the limb buds are well formed, nuclei have appeared close to the eperdimis (Figs. 5 and 6); and by the time the embryo has reached a length of 2.9 cm., the corium is differentiated (Fig. 9). Even as early as the last stage mentioned, the corium is raised in the regions of the primordia of the bands. This thickening increases so that in the 4.9 cm. embryo folds are found (Fig. 7). The folding continues as is shown in Figs. 12, 22, and 13, until finally the definitive condition is reached.

During the process described above for the band, the plate is being formed (1) by a thickening in the corium and (2) by ossification. The raising of the corium to form plates is begun in the posterior region of the band. There is no thickening in the anterior portion of the scute through the stage of the 5.5 cm. embryo, (Fig. 19), which is not true of the 6.7 cm. stage; and there is none in the posterior region even in the 6.7 cm. stage (Figs. 10 and 21). The plate primordia may be found in a 2.9 cm. embryo (Fig. 16), but not in the region where the epidermis is thickest (Fig. 17), which is also the region of the formation of the posterior hairs (Figs. 9 and 7). Fig. 20 shows a later stage, that of the 5.5 cm. embryo, than that of Fig. 16.

The bony formation begins in the pectoral shield about in the center, and later extends backward and to the sides. It next takes place in the banded region and is extended on back finally through the pelvic girdle. In the banded region the ossification takes place first in the center of the first or most anterior bands, it then spreads to the ends of the bands so that in a band where the development has not gone too far we have as many stages of ossification as there are plates. In the later stages, however, the difference in the stages are not so marked, so that the ossification appears to be practically in the same stage in nearly all of the plates.

A description of the ossification regions in the different aged embryos will make the above statements clearer. In the embryos of 5.5 and 6.7 cm. length, no ossification has taken place. In an embryo of 7.7 cm. length, there is no ossification in the pelvic shield, but in the pectoral shield there is a center of ossification which takes in an area that has a diameter equal to about one-third the distance across the shield and which is situated about in the center of the shield. In the banded region, the five anterior bands are ossified nearly to one-sixth of the distance from the ends, bands 6 and 7 are ossified but slightly, and bands 8 and 9 are not ossified at all. Practically the same condition exists in the 8.5 cm. and the 8.9 cm. embryos. In the 10 cm. embryo, however, the ossification has extended into the pelvic shield, but is found only in its center. In the pectoral shield and in the banded region, ossification is found in all except the outermost plates.

The ossification in a plate begins in the anterior half of the part not covered by the plate which is anterior to it (Fig. 13, X). Spots of bone appear between the hairs papillae, and these spots grow and fuse around the roots of the hairs, thus leaving rows of spaces in the early stages (Figs. 24, 25, 26, and 27). In the adult stage, however, the ossification has taken place throughout the corium, so that there are rows of pits marking the position of the hairs (Fig. 2, H. P. and P. H. P.).

COMPARISON

We find, then, that the early stages of the development of the integument of the armadillo are very similar to those described for the human integument by Pinkus (Keibel and Mall, '10). The periderm in both has cells which, in section, are spindle-shaped with deeply staining nuclei. These cells later flatten out into a continuous layer. There is also a deeper layer of cells which is at first characterized by broad thick cells with round or oval nuclei, but later is characterized by columnar cells with elongated nuclei. These cells give off an occasional cell between the two layers until finally a continuous layer, the stratum intermedium, is formed. Although the outer cells in both become cornified, the extremely horny scute is peculiar to the armadillo. Just beneath the horny layer are polygonal cells, and lower still, the columnar cells.

The corium in both is developed from the superficial portion of the somites. It has, at first, no very close connection with the epidermis, but as growth takes places, the connection is more intimate. Ridges and folds are produced in the corium of both; in the armadillo to form the plates and bands, in the human, the rete ridges, touch balls, gland ridges, and papillae.

The hairs are also formed in the same way. There is first a local increase of the number of nuclei in the epidermis. These nuclei are higher and more closely packed together than the adjoining ones. A gradual invagination of this thickened area takes place, making at first a columnar papilla which later develops into a bulb. Then connective tissue papilla comes from the corium, and gradually grows up into a concavity in the epidermal papilla. The hair then differentiates into the same layers and parts in both forms.

SUMMARY

The band in the adult integument is made up of three elements, (1) the plate, (2) the scute, and (3) the associated hair group.

The number of hairs at both the end and the sides of the plates varies.

The epidermis is early differentiated into two layers, the periderm and the stratum germinativum; and increase in thickness is begun by the addition of a layer of cells, the stratum intermedium, between the first two layers.

In the last stage worked out, the epidermis is composed of an outer horny stratum, which is not nucleated, and an inner germinal stratum, which is made up of a basal row of columnar cells, a region of polygonal cells, and an outer row of granular polygonal cells.

The corium, which comes from the superficial portion of the somite, is thrown into folds and ridges to form the scutes and bands.

Ossification begins in the anterior part of the animal first, and extends back and to the sides.

The ossification centers appear in little patches that grow together around the roots of the hairs, thus leaving rows of pits in the adult plate.

The two middle rows of pits found in the adult plate are not accounted for.

The hair begins as a local increase in the nuclei of the stratum germinativum. The thickened area thus formed invaginates to form the epidermal papilla.

The hairs of the scute develop in order from posterior to anterior, and the posterior hair is far in advance of the others.

The stages in the development of the integument of the armadillo follow very closely those of the human integument. The chief differences being that the armadillo has a very horny epidermis, marked off into definite scutes, and has bony plates in the corium.

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EXPLANATION OF PLATES

Sections shown in Figs. 3, 4, 5, and 6 are through the banded region of the embryos.

Plates VII, VIII, and IX are photographs.

Plate I

Fig. 1. Portion of band from left side showing, (1) three plates (23, 24, and 25), (2) scute-covered portion of the plate, (3) secondary scute, (4) primary scute, (5) inter-scute hairs, I. H., and (6) posterior hairs, P. H. x $2\frac{2}{3}$.

Fig. 2. Dorsal surface of a plate showing the two regions of the plate; four posterior hair pits, P. H. P.; four inter-scute hair pits on the left side, and five inter-scute hair pits on the right side, H. P.; and two middle rows of pits. x $2\frac{2}{3}$.

Fig. 3. Section showing undifferentiated ectoderm. x 840.

Plate II

Fig. 4. Cells in epidermis beginning to flatten out at the surface; E, flattened cell; X, cell beginning to flatten. x 1066.

Fig. 5. Two-layered condition of epidermis. E, epitrichium; S. G., stratum germinativum. x 520.

Fig. 6. Beginning of the intermediate layer at x. E, epitrichium; S. G., stratum germinativum. x 520.

Plate III

Fig. 7. A longitudinal section of the integument of a 4.9 cm. embryo to show the folding to form the band, and the beginning of the hair. x 77¼.

Fig. 8. High power drawing of longitudinal section from a 2.7 cm. embryo to show the thickening of the epidermis. x 375.

Plate IV

Fig. 9. Longitudinal section from a 2.9 cm. embryo to show the thickening of the epidermis. G. L., germinal layer; E, epitrichium; Y, beginning of scute. x 200.

Fig. 10. A cross section from a 6.7 cm. embryo through the posterior end of the scute showing at the top two hairs of one scute, and at the bottom, three of the next. x 177.

Plate V

Fig. 11. High power drawing of the second hair follocle of Fig. 10. P, the dermal papilla. x 568.

Fig. 12. A longitudinal section of one plate and a portion of the two adjoining ones, showing folding and stage of development of the posterior hair of a 6.7 cm. embryo. x 46⅔.

Plate VI

Fig. 13. A longitudinal section from a 7.7 cm. embryo showing folding, formation of plates at x; and layers of the skin. x 46⅔.

Fig. 14. High power drawing from the section of Fig. 13 through the epidermis in the region of the root of the hair. H, horny layer; S. G. stratum granulosum; I. C. intermediate cells; C. C. columnar cells; C, corium; H. hair. x 233.

Plate VII

Fig. 15. A longitudinal section from a 2.7 cm. embryo showing a stage between that of Fig. 9 and Fig. 7. x 100.

Fig. 16. A transverse section of a band to show the thickening of the corium in the region of three primary and three secondary scutes in a 2.9 cm. embryo. x 102.

Fig. 17. Section from the same embryos that on Fig. 16 to show that the corium is not thickened in the region of greatest scute formation. x 92.

Plate VIII

Fig. 18. A longitudinal section of a 4.4 cm. embryo showing a slightly later stage than that in Fig. 7. x 82.

Fig. 19. A transverse section from the anterior region of a scute showing that there is no thickening of the corium. From a 5.5 cm. embryo. x 61.

Fig. 20. A transverse section of a band of the same embryo as that shown in Fig. 19 to show thickening of the corium in the region of the anterior hairs. x 51.

Plate IX

Fig. 21. A transverse section from the same embryo as shown in Figs. 19 and 20, showing the four posterior hairs of one plate. x 53.

Fig. 22. A longitudinal section from the same embryo showing the stages of development of the interscute hairs. x 53.

Fig. 23. The posterior hair of the plate shown in Fig. 22. x 64.

Plate X.

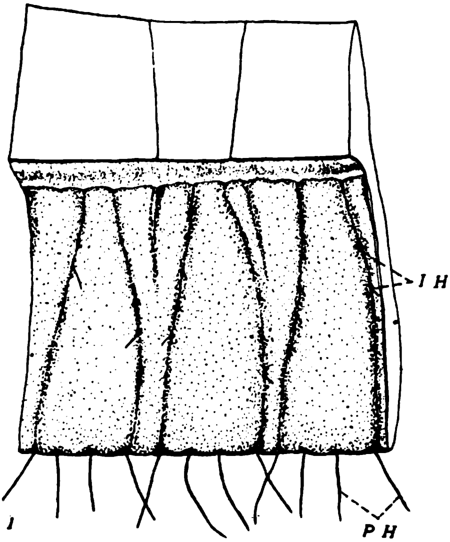
Fig. 24. Two plates from a KOH-cleared specimen to show early plate formation. From the region ¼ the distance from the left and of the first band of a 8.9 cm. embryo. x 24.75.

Fig. 25. The middle region of the same band as that in Fig. 24 to show further development. x 24.75.

Fig. 26. Three plates from a KOH-cleared specimen to show later plate formation and posterior hairs. From the end of the first band of a 10 cm. embryo. x 12.

Fig. 27. Two plates from the center of the same band as that shown in Fig. 26. The holes in the bone are where the roots of the hairs are. x 11.25.

PLATE I



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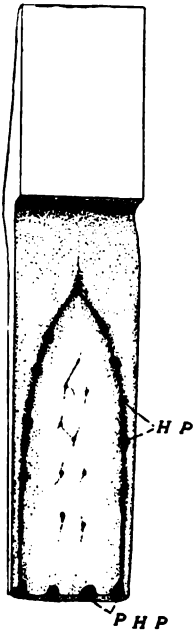

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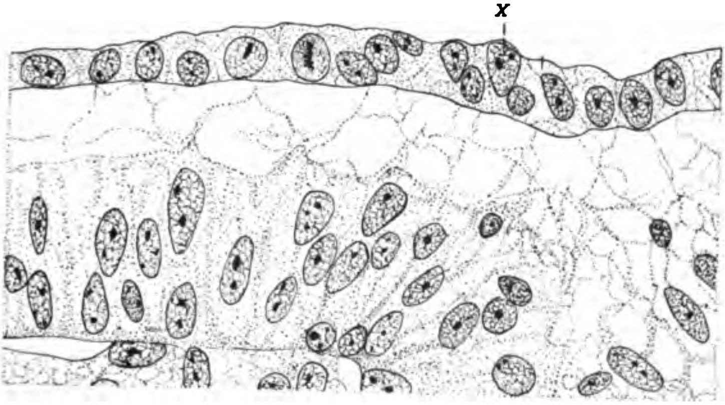

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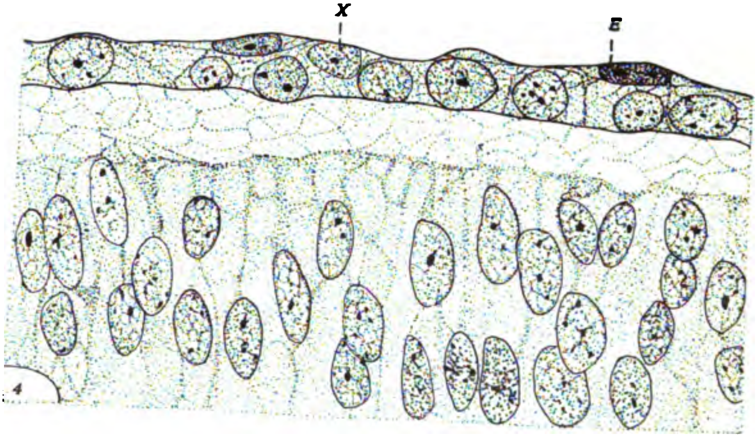

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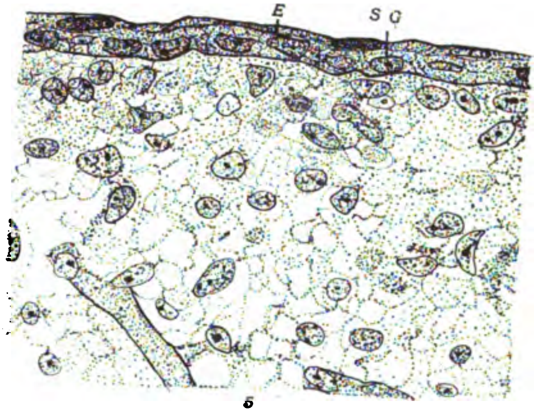

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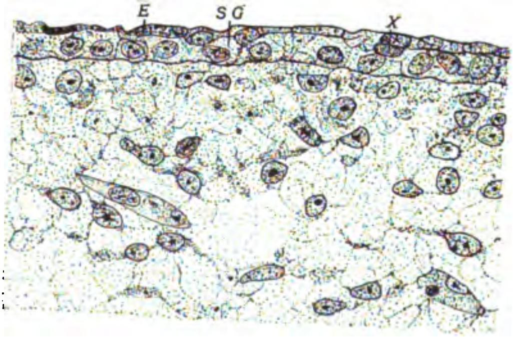

PLATE III

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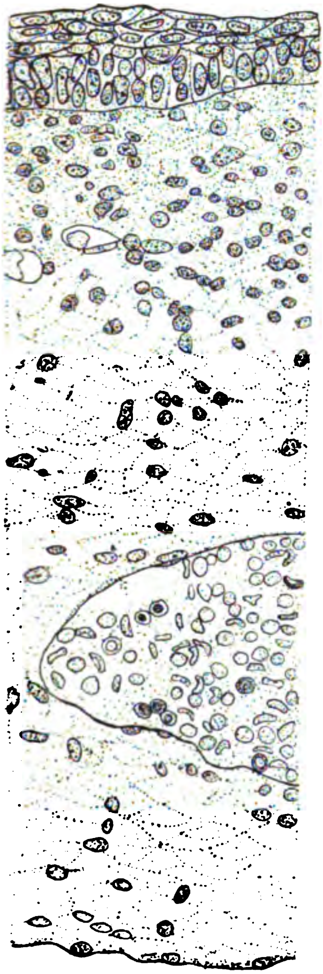

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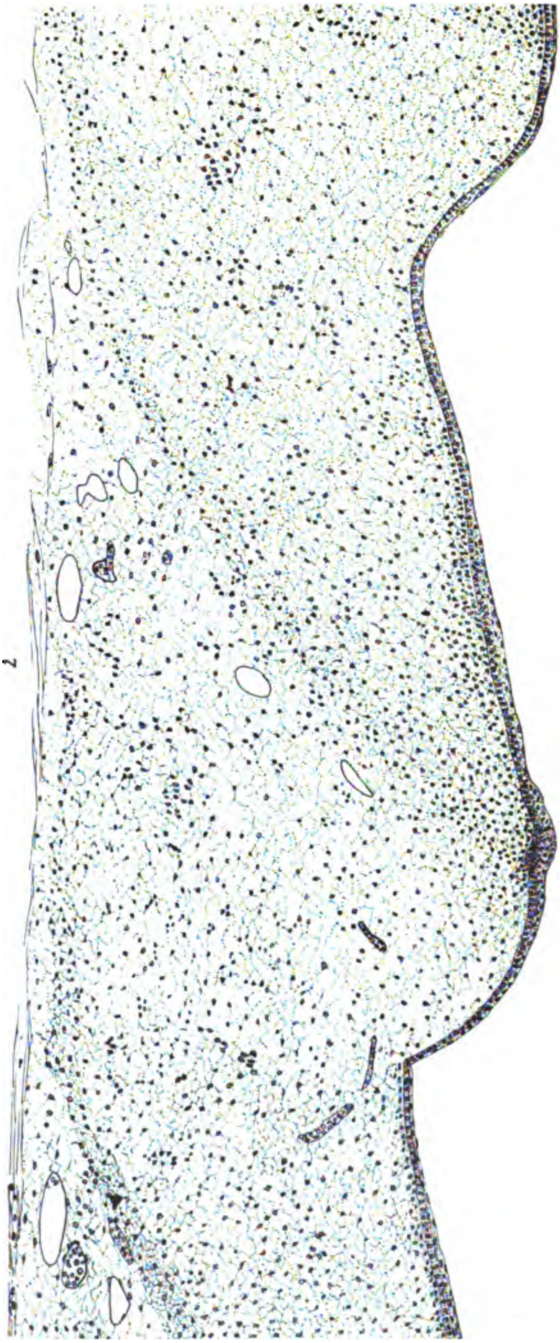

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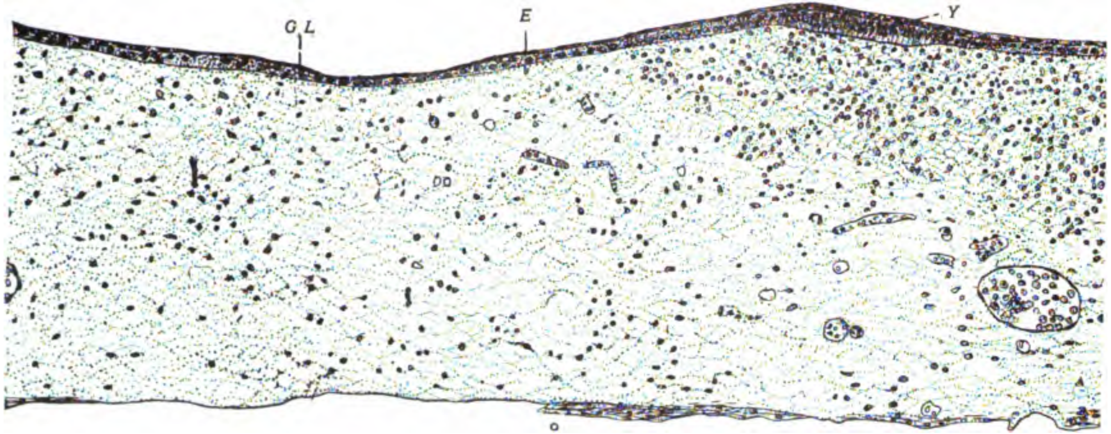

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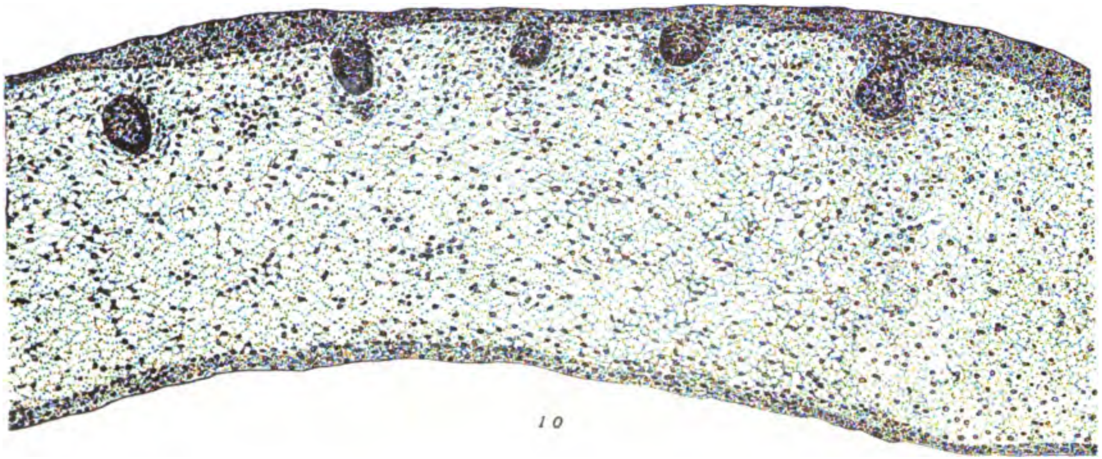

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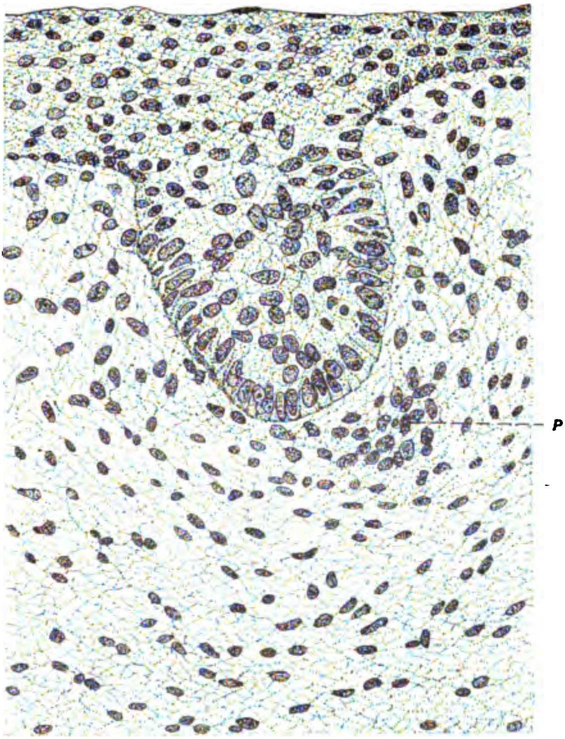

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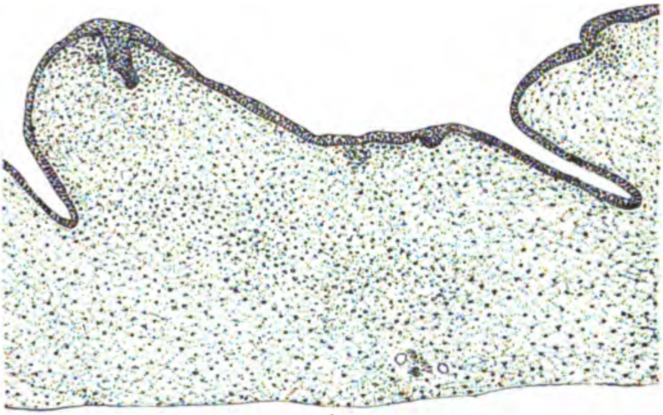

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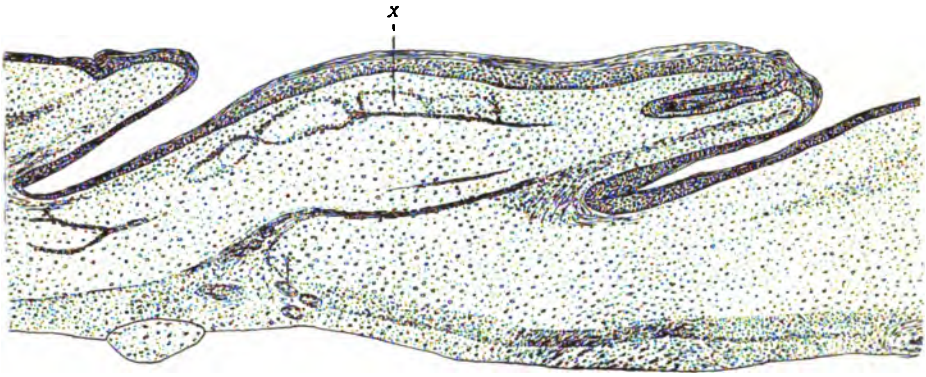

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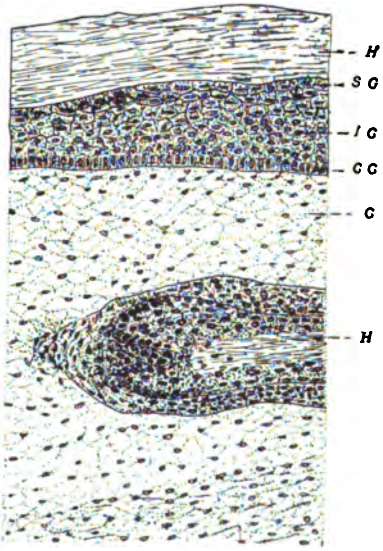

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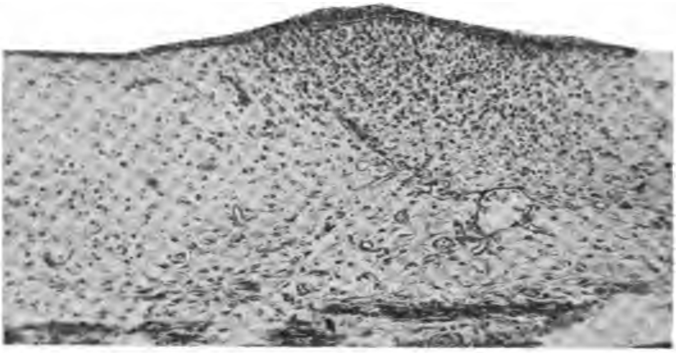

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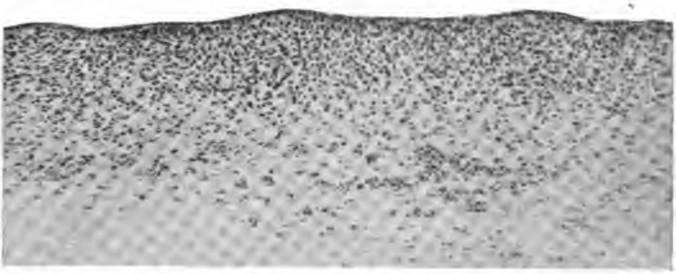

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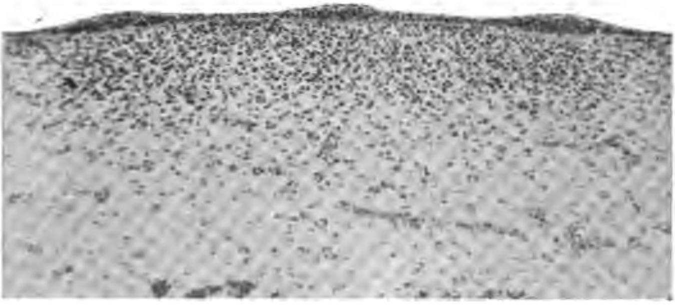

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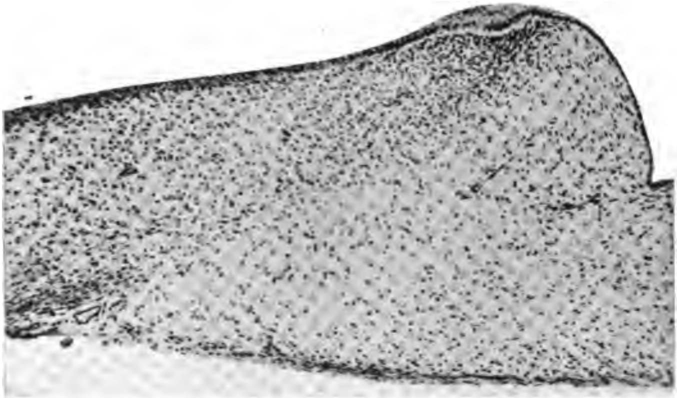

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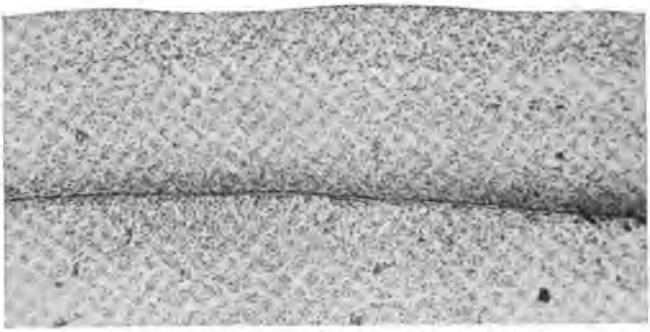

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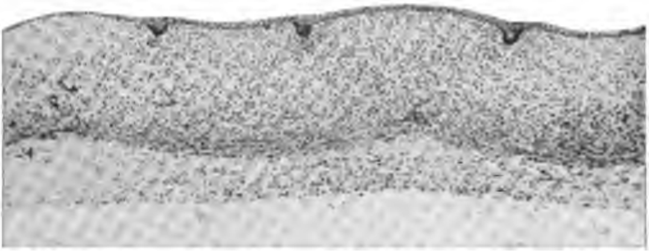

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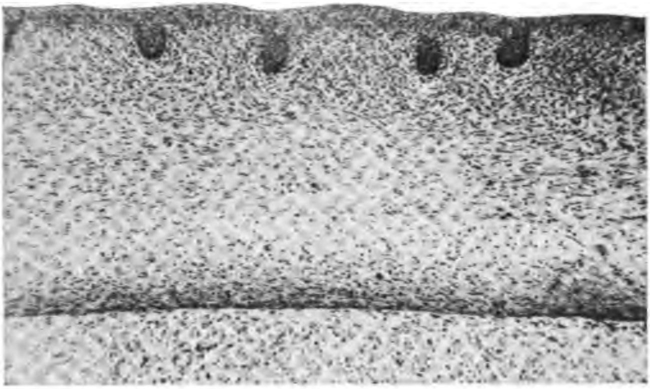

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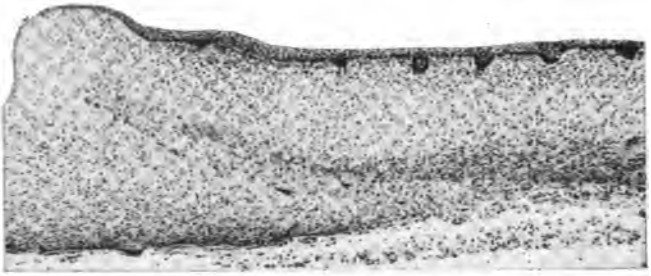

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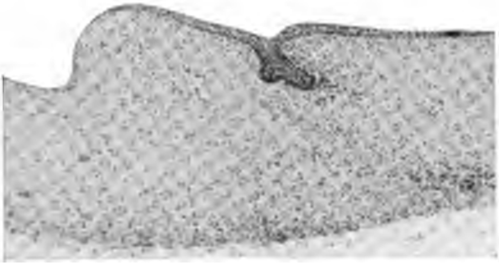

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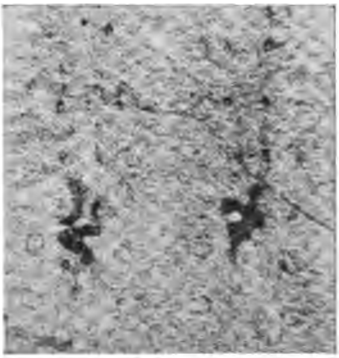

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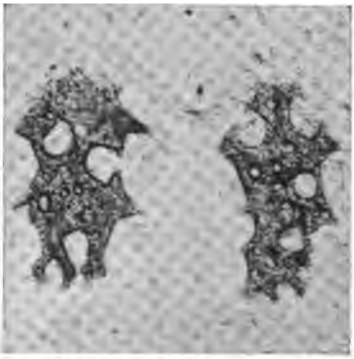

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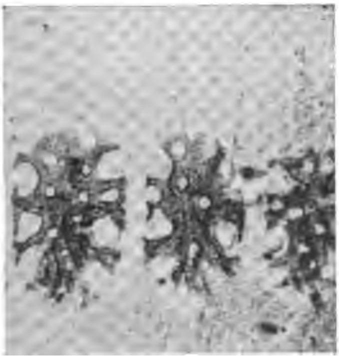

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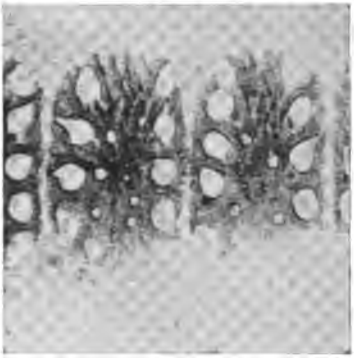

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THE ERROR-RISK OF THE MEDIAN COMPARED WITH THAT OF THE ARITHMETIC MEAN

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Cultivated mind is the guardian genius of democracy. . . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.
President Mirabeau B. Lamar.

The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.
President Sam Houston.

THE ERROR-RISK OF THE MEDIAN COMPARED WITH THAT OF THE ARITHMETIC MEAN.

BY EDWARD L. DODD.

If several leaves * from a tree have been collected, the question arises: What is the typical or representative length of leaf for this tree? Or, if several measurements have been made of the same quantity, the question arises: What shall we accept as an approximation for the "true value" of the unknown magnitude? The "typical value" of the length of a leaf and the "true value" of a magnitude exist usually only as mathematical abstractions. Nevertheless, if we arrange the leaves in the order of their magnitude—as to length—it appears more reasonable to select the middle leaf as the typical leaf than to select the first and shortest leaf. The length of this middle leaf is called the *median* of the lengths. On the other hand, it is not so clear that the median is preferable to the average—the *arithmetic mean*—of the lengths.† In fact, it seems probable that sometimes the arithmetic mean is to be preferred, and sometimes the median. Nevertheless, we may with advantage investigate these two functions of the measurements from the standpoint of general statistical theory.

In this paper, the Gaussian Probability Law will be used as a criterion. It is not pretended that all distributions follow closely this law in its most simple—symmetric—form. But the Gaussian Law has been commonly accepted as representing the ideal distribution, both on account of theoretic considerations and by reason of experimental verifications. For example; an urn contains N balls, of which M are white. The balls are mixed, and n balls are drawn—where $n<N$—and then returned to the urn. Of these, m are found to be white; and thus m/n is a "measurement" of the "true value," M/N, which in this case is *exactly known*. The distribution of the repeated "measurements" about the "true value," M/N can be studied experimentally.

For mathematical treatment, it is assumed that a "true value" or "typical value" or "normal value" exists: let this be denoted by a. The difference, $a-m$, where m is a measurement, is called the *error*‡ of that measurement. The Gaussian Law assumes the existence of a *measure of precision*, h, for a set of measurements made under like circumstances; and then states that the probability that the error of a measurement will lie between x_1 and x_2 is

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*See King's Elements of Statistical Method, p. 101, Macmillan (1912).

†For an elementary discussion of the advantages and disadvantages of the arithmetic mean, the median, the mode, etc., see King, loc. cit. Chap. XII.

‡Such terms as "deviation," "departure," are also used to designate $a-m$ or $m-a$.

$$p = \frac{h}{\sqrt{\pi}} \int_{x_1}^{x_2} e^{-h^2x^2} dx. \tag{1}$$

In the language of "large numbers," this means that when the number, *n*, of measurements is large, it is to be expected that about *pn* of these measurements will have errors greater than x_1 and at the same time less than x_2. This law (1) is frequently expressed as follows: The probability that the error of a measurement will lie between x and $x+dx$ is

$$\frac{h}{\sqrt{\pi}} e^{-h^2x^2} dx. \tag{2}$$

Let

$$\Theta(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt. \tag{3}$$

Then from (1) the probability that the error of a measurement will lie between $-x$ and x is $\Theta(hx)$.

As preliminary to the treatment of the median, let us find the probabilty that: The first error—the error of the first measurement—will lie between x and $x+dx$; the second error will be less than the first error; and the third error will be greater than the first error. The probability of the first part of this compound event is given by (2). For the moment, suppose that x is positive, and that the first error is exactly x. Then the probability that the second error will be less than the first error,— i. e., that the second error will lie between $-\infty$ and x,—is $\frac{1}{2}+\frac{1}{2}\Theta(hx)$. The probability that the third error will be greater than the first error is $\frac{1}{2}-\frac{1}{2}\Theta(hx)$. The probability of the compound event is then

$$\frac{1}{4}\frac{h}{\sqrt{\pi}}[1-\Theta^2(hx)]e^{-h^2x^2} dx; \tag{4}$$

that is, the product of the probabilities of the three components.

The restriction that x be positive is not essential; since $\Theta(-x) = -\Theta(x)$. The supposition that the first error is *exactly* x is a common device, incident to the extension of the law for compound probability—deduced from the consideration of a *finite* number of possibilities—to the *continuum* with its *infinity* of real numbers. We do not deny that such an extension involves some axiom.

If now $2n+1$ measurements are to be made, the probability that: The first error will lie between x and $x+dx$; the next n errors will be (algebraically) less than the first error; and the last n errors will be greater than the first error, is obtained from (4) by raising $\frac{1}{4}$ and the bracket each to the *nth* power. If, however, we simply require that *some unspecified one* of the $2n+1$ errors shall lie between x and $x+dx$, and that of the $2n$ remaining errors just n errors shall be less than x, the coefficient $(2n+1)\frac{(2n)!}{(n!)^2}$ is also needed.

Suppose now that the error of the median of $2n+1$ measurements is x. Then the errors of n of the measurements must be (algebraically) less than or equal to x; and the errors of the remaining n measurements must be greater than or equal to x. The probability that the error of the median of $2n+1$ measurements will lie between x_1 and x_2 is, then,

$$\frac{(2n+1)!}{4^n(n!)^2}\frac{h}{\sqrt{\pi}}\int_{x_1}^{x_2}[1-\Theta^2(hx)]^n e^{-h^2x^2}dx. \tag{5}$$

If we set

$$N=\frac{(2n+1)!}{4^n(n!)^2};\ t=hx;\ t_1=hx_1;\ t_2=hx_2; \tag{6}$$

this becomes

$$\frac{N}{\sqrt{\pi}}\int_{t_1}^{t_2}[1-\Theta^2(t)]^n e^{-t^2}dt. \tag{7}$$

An interesting verification of (5) and (7) consists in setting $x_1=-\infty$, $x_2=+\infty$; and introducing the change of variable,

$$u=\Theta(t),\ du=\frac{2}{\sqrt{\pi}}e^{-t^2}dt.$$

Then (7) becomes

$$N\int_0^1(1-u^2)^n du. \tag{8}$$

By the substitution, $u=\sin\phi$, this can be shown† to be equal to unity, the symbol for certainty.

We shall now make use of the conception of the *probable value*. To illustrate: If a gambler is to receive one dollar if he throws an ace with a die, two dollars if he throws a two-spot, etc., his *expectation* on a single throw is defined as

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†Peirce—A Short Table of Integrals, p. 62.

$$\tfrac{1}{6}(1)+\tfrac{1}{6}(2)+\tfrac{1}{6}(3)+\tfrac{1}{6}(4)+\tfrac{1}{6}(5)+\tfrac{1}{6}(6)=3\tfrac{1}{2}$$

dollars; and this is also called the *probable value* of his intake. It is obtained by multiplying each possible prize by its probability—in this case, $\frac{1}{6}$—and taking the sum of the products. It may be roughly described as the expected average intake. The gambler's "expectation" in sixty throws is $60\times 3\frac{1}{2}=210$ dollars; and this is exactly what he will receive if he throws an ace ten times, and each other spot just ten times.

Now let the absolute or positive value of an error, x, be called the *absolute error*, and be denoted by $|x|$. Then, in accordance with the usual generalization, the *probable value* of the *absolute error* of the *median* is obtained by multiplying the integrand in (5) by $|x|$, and taking $x_1=-\infty$, $x_2=\infty$; or, what is equivalent, multiplying the integrand by $2x$, and taking $x_1=0$, $x_2=\infty$.

We can obtain directly a theorem comparing the probable value of the absolute error of the median with that of the arithmetic mean; but we shall obtain it as a corollary to a theorem on error-risk.

In dealing with *error-risk*—"*Fehlerrisiko*"—Czuber* introduces a risk-function with the following characteristics:

$$v(-x)=v(x);\ \text{ and } v(x')>v(x) \text{ if } |x'|>|x|. \tag{9}$$

It is to be supposed also that v is not negative, and that $v(x)e^{-h^2x^2}$ is integrable from 0 to ∞. The most simple risk-functions are, perhaps,

$$|x|,\ x^2,\ |x^3|,\ x^4, \text{ etc.}$$

By the *error-risk* is meant the *probable value* of $v(x)$, where x is the error of a measurement or of a function of the measurements. Hence, from (5) and (6), the *error-risk* of the *median* of $2n+1$ measurements is

$$P_1=\frac{2N}{\sqrt{\pi}}\int_0^\infty v\left(\frac{x}{h}\right)[1-\Theta^2(x)]^n e^{-x^2}dx. \tag{10}$$

This is obtained by first making the substitution, $hx=t$; and then, $t=x$.

Now, the arithmetic mean of $2n+1$ measurements, each subject to the Gaussian Law (1) with measure of precision, h, is itself† subject to the Gaussian Law with measure of precision,

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*Wahrscheinlichkeitsrechnung I. p. 267.

$$H=h\sqrt{2n+1}. \tag{11}$$

Hence, the error-risk of the arithmetic mean of $2n+1$ measurements is

$$P=\frac{2\sqrt{2n+1}}{\sqrt{\pi}}\int_0^\infty v\left(\frac{x}{h}\right)e^{-(2n+1)x^2}dx. \tag{12}$$

It will now be shown that P is less than P_1 for each (positive integral) value of n. In the technical sense, as used here, the "*risk*" of *error* in accepting the *arithmetic mean* is, then, *less* than in accepting the *median*. In other words, it is to be expected that the error of the arithmetic mean will be numerically less than that of the median in Gaussian distributions.

To prove this, consider the two curves, suggested by (12) and (10), viz.,

$$y=F(x)=\frac{2\sqrt{2n+1}}{\sqrt{\pi}}e^{-(2n+1)x^2}, \tag{13}$$

$$y=f(x)=\frac{2N}{\sqrt{\pi}}[1-\Theta^2(x)]^n e^{-x^2}. \tag{14}$$

In what follows, we shall consider only values of $x>0$ or $x=0$. We shall first prove that $F(0)>f(0)$. Stirling's formula, in closed form*, is

$$n!=\sqrt{2\pi n}\,n^n e^{-n+\frac{\theta}{12n}},\ 0<\theta<1. \tag{15}$$

Then, from (6),

$$N=\frac{(2n+1)(2n!)}{4^n(n!)^2}=\frac{(2n+1)(\sqrt{4\pi n}(2n)^{2n}e^{-2n+\frac{\theta'}{24n}}}{4^n(2\pi n)n^{2n}e^{-2n+\frac{\theta}{6n}}}$$

$$=\frac{2n+1}{\sqrt{\pi n}}e^{\frac{\theta'}{24n}-\frac{\theta}{6n}}.$$

From this, it follows that

$$e^{-\frac{1}{6n}}\sqrt{\frac{2}{\pi}}<\frac{N}{\sqrt{2n+1}}<\sqrt{\frac{2n+1}{\pi n}}\,e^{\frac{1}{24n}}.$$

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†Czuber, loc. cit. p. 262, gives a more general statement of this principle.

*Cesaro—Corso di analisi algebrica, pp. 270, 480.

And hence, when $n > 1$,

$$\tfrac{1}{2} < \frac{N}{\sqrt{2n+1}} < 1; \qquad (16)$$

which is, indeed, also satisfied when $n=1$. Hence, $F(0)>f(0)$; since $\Theta(0)=0$.

We shall next prove that $F(x)<f(x)$ when $x>2$. In other words, beyond $x=2$ the curve, $y=F(x)$, lies wholly below the curve, $y=f(x)$. Since $\Theta(\infty)=1$,

$$1-\Theta(x)=\frac{2}{\sqrt{\pi}}\int_x^{\infty} e^{-x^2}\,dx.$$

Now, if $x>2$,

$$8xe^{-x^2}<1;$$

and thus,

$$2\int_x^{\infty}\left(4xe^{-x^2}\right)e^{-x^2}dx<\int_x^{\infty}e^{-x^2}dx.$$

But the left member is equal to $2e^{-2x^2}$; and hence,

$$1-\Theta(x)>2e^{-2x^2};$$

$$[1-\Theta^2(x)]^n>2^n e^{-2nx^2}.$$

This, with (16), proves that $F(x)<f(x)$ when $x>2$.

Hence, the curves (13) and (14) must intersect at least once—as stated before, we are not considering negative values of x— and, if they intersect twice, they must intersect at least three times. By the indirect method, we shall prove that the curves cannot intersect in three points; and hence, they intersect but once. Suppose, then, that there are three points of intersection. And let

$$D(x)=F(x)-f(x);\quad c^n=\frac{N}{\sqrt{2n+1}},\ c>0. \qquad (17)$$

Then

$$D(x)=\frac{2}{\sqrt{\pi}}e^{-x^2}\sqrt{2n+1}\left\{e^{-2nx^2}-c^n[1-\Theta^2(x)]^n\right\}.$$

One factor of $D(x)$ is

$$g(x)=e^{-2x^2}-c[1-\Theta^2(x)];$$

and the product of the remaining factors is positive. Then, since $D(x)$ has three positive roots, $g(x)$ also has three positive roots; and

$$g'(x) = -4xe^{-2x^2} + 2c\,\Theta\,(x)\frac{2}{\sqrt{\pi}}e^{-x^2}$$

has two positive roots, by Rolle's Theorem.
Thus,

$$G(x) = -xe^{-x^2} + \frac{c}{\sqrt{\pi}}\,\Theta\,(x)$$

has two positive roots. But $G(0)$ is also zero. And hence

$$G'(x) = (2x^2-1)e^{-x^2} + \frac{2c}{\pi}e^{-x^2}$$

has two positive roots. But

$$2x^2 - 1 + \frac{2c}{\pi}$$

can not be zero for more than one positive value of x. Thus, the supposition that (13) and (14) intersect in more than one (positive) point, leads to an impossibility.

Let b be the abscissa of the point of intersection, and let A be the area between the two curves (and the Y axis) from $x=0$ to $x=b$. Then, the area between the two curves from $x=b$ to $x=\infty$ is also A; since the total area beneath each curve is unity—see (8).

Now, from (10), (12), (13), (14), (17),

$$P = \int_0^\infty F(x)v\left(\frac{x}{h}\right)dx = \int_0^b D(x)v\left(\frac{x}{h}\right)dx + \int_0^b f(x)v\left(\frac{x}{h}\right)dx + \int_b^\infty F(x)v\left(\frac{x}{h}\right)dx; \qquad (18)$$

$$P_1 = \int_0^\infty f(x)v\left(\frac{x}{h}\right)dx = \int_0^b f(x)v\left(\frac{x}{h}\right)dx + \int_b^\infty F(x)v\left(\frac{x}{h}\right)dx + \int_b^\infty -D(x)v\left(\frac{x}{h}\right)dx. \qquad (19)$$

But the first integral on the right in (18) is less than $Av\left(\frac{b}{h}\right)$; since, by (9), v is an increasing function of x. The last two integrals in (18) are the same as the first two integrals on the right in (19). In the last integral of (19), the function $-D(x)$ is positive*; since $F(x)<f(x)$ when $x>b$. This integral is greater than $Av\left(\frac{b}{h}\right)$ Hence

$$P<P_1. \tag{20}$$

THEOREM

The error-risk of the median of an odd number† of measurements, each subject to the Gaussian Law (1), *is greater than the error-risk of the arithmetic mean of these measurements.*

COROLLARY

The probable value of the absolute error of the median of an odd number† of measurements, each subject to the Gaussian Law (1), *is greater than that of the arithmetic mean of these measurements.*

This corollary is also evident from mechanical considerations,—when it has been proved that $F(0)>f(0)$; and that the curves, $y=F(x)$ and $y=f(x)$, intersect but once. For the two probable values, P and P_1 are simply the abscissas of the centers of gravity of the areas beneath these two curves, respectively.

Now a center of gravity problem may be looked upon as a problem of finding an *average*,—involving, perhaps, a passage to a limit. And there is enough resemblance between a *probable value* and an *average* to lead to a suspicion that a method of comparison based upon probable value might favor the arithmetic mean, M, above all other functions of the measurements. That this is not indeed the case would appear from the fact that *there are functions*** with an *error-risk smaller* than that of the *arithmetic mean.* And futhermore, these comparisons based upon probable value are in harmony—so far as they go—with comparisons obtained by another method††.

The median is not one of the functions considered by Czuber‡ in his treatment of error-risk. For, although the median is a continuous function of its arguments—the measurements—the first partial derivarives do not always exist; and thus there are points about which the median can not be given a Taylor's development. To illustrate: Suppose the measurements are x, y, and z; and that the median *is $F(x, y, z)$; and suppose $x<z$. If, now, $x<y<z$, then the partial derivative, $F_y'(x, y, z)=1$. But, if $y=x$, the forward F_y' is equal to 1; whereas, the backward F_y' is equal to 0. And thus, at this point, F_y' itself does not exist. Czuber considers functions that can be given a Taylor's development.

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*It might be zero at just one point, so far as has been proved; but this does not affect the argument.

†The degenerate case, n=1, is not here considered.

**As found in a former investigation. See Monatshefte fuer Mathematik und Physik, 1913, p. 270. For example: $\left(1-\frac{1}{n^2}\right)M$, when n is large enough,—using (8) p. 270.

††Annals of Mathematics, June 1913, pp. 186-198.

‡Loc. cit. p. 275.

The attempt has been made to show that the Gaussian Probability Law* is a logical consequence of the "Principle," that the arithmetic mean is the "most probable value" of the unknown true value. But Bertrand† gives an example to show that the Law and "Principle" are not strictly compatible. What *function* of the measurements the *Gaussian Law endorses* above all other functions is *not at present known*. And it *may* well *be* that there is *no such function*.

The theorem of this paper does not recommend the use of the arithmetic mean in preference to the median under all circumstances; but merely when it is assumed that the distribution is a Gaussian distribution.

But, in view of this theorem, if there is any reason for supposing —in a particular case—that the median gives a more satisfactory result than the arithmetic mean, this is also a reason for supposing that the distribution is not Gaussian. And thus, any formula for "probable error" or like expression deduced from the assumption of the Gaussian Law should be viewed with considerable suspicion, so far as its application to the particular case is concerned.

***This F is entirely distinct from that used in (13).**

†Calcul des Probabilites (1889) p. 180.

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